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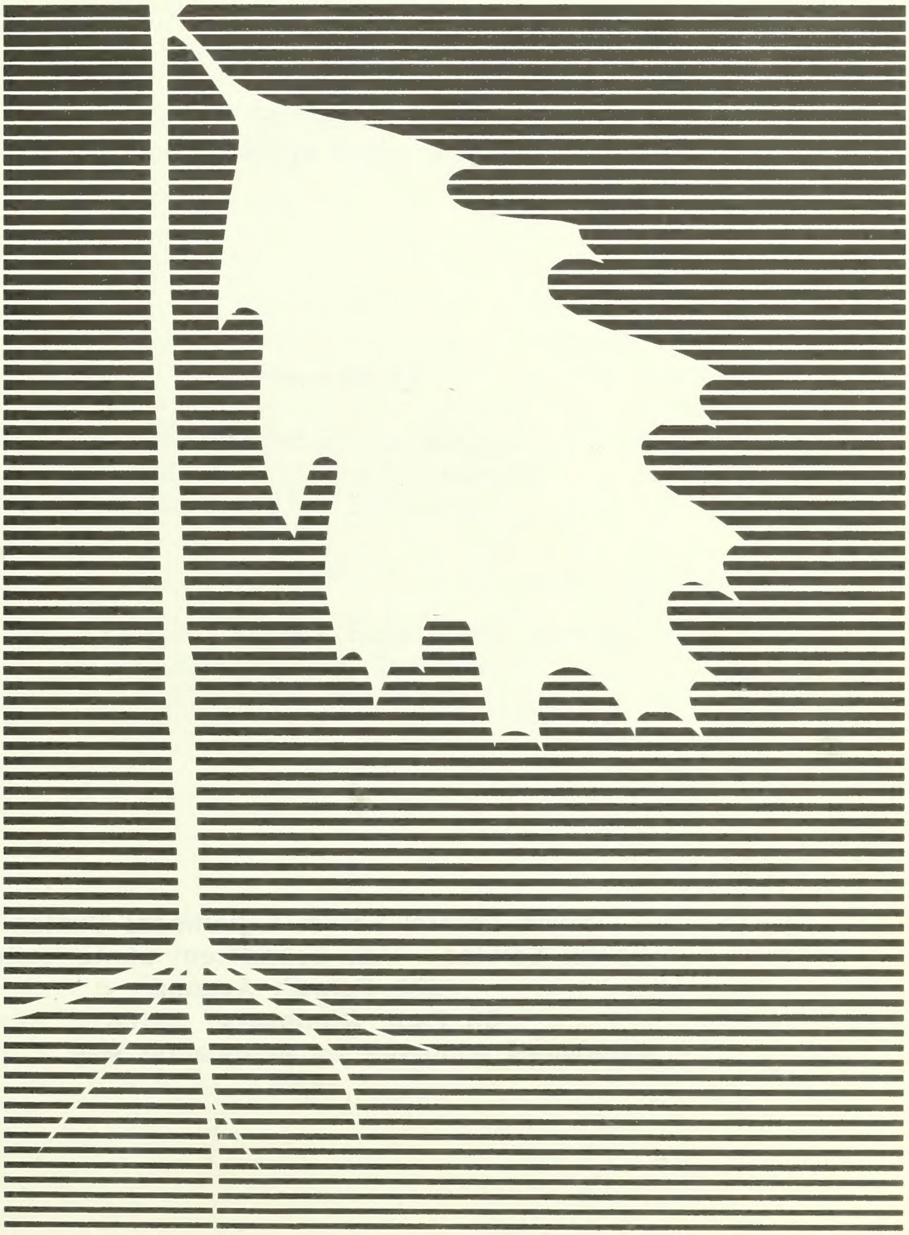
Third Workshop on Seedling Physiology and Growth Problems in Oak Plantings

(Abstracts)



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North Central Forest Experiment Station
Forest Service - U.S. Department of Agriculture
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THIRD WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTINGS, CARBONDALE, ILLINOIS, FEBRUARY 12-13, 1986 (ABSTRACTS)

Edited by
J. W. Van Sambeek, George Rink, and Paul S. Johnson

Sponsored by

Department of Forestry
Southern Illinois University
Carbondale, Illinois

and

North Central Forest Experiment Station
USDA, Forest Service
St. Paul, Minnesota

PREFACE

On February 12-13, 1986, a group of foresters, forest scientists, tree physiologists, horticulturists, and entomologists met at Southern Illinois University-Carbondale for the Third Workshop on Seedling Physiology and Growth Problems in Oak Plantings. The first workshop, held in 1979, was prompted by an increase in interest among North American foresters in planting oak. This continuing interest has resulted in an initative to develop integrated management guidelines for the central hardwoods, especially the oak-hickory forest type. The third workshop provided a forum for exchange of ideas and research results in three subject areas: (1) oak physiology and genetics, (2) oak seedling propagation and production methods, and (3) field performance of planted oaks. Abstracts of papers given at the workshop are presented here, as well as, those of our southern colleagues who could not attend because of a major ice storm that occurred the preceding weekend.

Jerry Van Sambeek, workshop coordinator, gratefully acknowledges the assistance of the following session moderators: Paul S. Johnson, George Rink, Carl A. Budelsky, and Phil Pope. In addition, the workshop coordinators are grateful to Mel Larson and Ohio State University for accepting the responsibility of hosting our fourth workshop in 1989.

Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

Except for those written by North Central Forest Experiment Station employees, these abstracts have not gone through the Station's regular editorial process. Each author is responsible for the accuracy and style of his own paper. Statements do not necessarily reflect the policies of the U. S. Department of Agriculture.

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VARIATION IN GROWTH AMONG WHITE OAK SEEDLINGS IN A HALF-SIB PROGENY TEST

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A white oak (*Quercus alba* L.) progeny test was initiated in April 1983, using 2-0 seedlings from 12 sources. Progeny of six individual trees in southern Illinois or Indiana (families), of four stand collections, and of two check seedlots were tested. In fall 1985, after three growing seasons, survival averaged 78 percent. Mortality appeared to be randomly distributed, and survival differences among families were not significant. There was no correlation between survival and basal stem diameter at outplanting.

Height differences among open-pollinated families were not statistically significant primarily because of the low number of families represented in this test. Expressed on a plantation mean basis, however, there was a 35-percent difference in height growth between the fastest and slowest growing families in the third growing season. Height growth averaged 55.4 cm after three growing seasons. By contrast, there were significant differences in basal stem diameter among families at outplanting. The differences persisted through the third growing season with a 45-percent difference in average diameter growth between the fastest and slowest growing families. After the third growing season, the correlation between height and basal stem diameter was 0.73, indicating that the tallest trees had the greatest diameter growth. There was no correlation, however, between basal stem diameter at outplanting and third-year height growth, indicating that outplanting basal stem diameter is not a good indicator of future growth potential. The pattern of variation among provenances was similar to that among families.

AN OVERVIEW OF OAK TREE IMPROVEMENT PROGRAMS IN INDIANA

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The Indiana Department of Natural Resources, Division of Forestry, has initiated tree improvement programs for four oak species. In 1983, a provenance/progeny test plantation of cherrybark oak (Quercus falcata var. pagodaefolia Ell.) was established using thirty half-sib families from five southern states and Indiana. Plans are to convert this plantation into a seedling seed orchard.

A limited range white oak (Q. alba L.) provenance/progeny test was established at six locations in 1984. Up to seventy half-sib families (five trees per stand) from Indiana, southern Illinois, and Missouri were included in three Indiana plantings. The purpose of these plantations was (1) to quantify the levels and patterns of genetic variation within the Indiana white oak population and (2) to serve as populations for future tree improvement activities such as seedling seed orchard conversion and/or plus-tree selection work. Using these same families, additional plantings were established by the USDA Forest Service in southern Illinois and by Michigan State University at the Kellogg and Rust Experimental Forests.

A clonal program for northern red oak (Q. rubra L.) was begun in 1984 using scionwood from eighty nine plus-trees from throughout Indiana. Greenhouse grafting success was 92 percent in the spring of 1985. Grafts were used to establish a closely-spaced, seed orchard/clone bank in the spring of 1986. Seed for progeny testing will be collected from the orchard and progeny test results will be used to rogue the orchard.

In 1985, eighty half-sib families of English oak (Q. robur L.) from West Germany, France, and Yugoslavia were established in six provenance/progeny test plantations. Also included were seedlings from six Michigan State University seedlots and a single commercial check seedlot. The Indiana plantation will provide information on the potential value of this exotic in Indiana. The five other provenance/progeny tests were established by Michigan State University at two locations, the Ohio Department of Natural Resources, Iowa State University, and the University of Maine.

A MORPHOLOGICAL INDEX FOR STUDIES ON OAK SEEDLINGS

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Several morphological indices have been developed to relate morphological measurements to biochemical, physiological, and anatomical events or processes in plants. The leaf plastochron index (LPI) has been widely used in developmental studies of trees. However, morphological indices used for trees with indeterminate shoot growth cannot be effectively applied to trees with determinate or semi-determinate shoot growth such as oak (Quercus spp.). The need for a suitable morphological index for use in oak studies is probably greater than for most other species because of their extreme variability.

A Quercus morphological index (QMI) based on simple leaf and stem growth measurements has been useful in our studies on northern red oak (Q. rubra L.) seedlings. Three distinct stages have been defined for each flushing episode--linear stem elongation (Slin), linear leaf elongation (Llin), and flush lag (Lag). The QMI is currently used at our laboratories in several ways: (1) to ensure uniformity of morphological stages of development in parallel studies of the same seed source at different locations, (2) to compare seed sources from year to year, (3) to compare growth of different species within a defined environment, (4) to determine shifts in plant development due to different treatments or environments, and (5) to relate the morphological stages of oak seedling development to biochemical, physiological, and anatomical events and processes.

We hope that other research groups studying oak will also use the QMI and/or a similar morphological index to standarize research techniques and facilitate the transfer of research information between various research groups and geographical regions. Currently, we are applying the QMI to our oak studies on (1) apical bud development, (2) anatomical and physiological changes in developing leaves, (3) photosynthesis and respiration of developing leaves, (4) photosynthate distribution and quantification of photosynthetic products, (5) herbicide tolerance, and (6) vegetative propagation and physiology of rooting oak cuttings.

PHOTOSYNTHESIS AND RESPIRATION OF NORTHERN RED OAK SEEDLINGS

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Slow growth and shoot dieback of northern red oak (*Quercus rubra* L.) seedlings may be the result of an unfavorable balance between photosynthesis and respiration. We grew red oak seedlings in a controlled environmental chamber to better understand carbon dioxide exchange and growth of recurrent flushing seedlings at various stages of growth. Carbon dioxide exchange measurements at several light intensities were made on an attached median leaf within each flush at each of nine growth stages that were identified using the *Quercus* morphological index (QMI). An optimized sampling strategy was used to choose light levels to minimize variance of photosynthetic and respiration rate estimates. Light saturated photosynthesis and dark respiration were determined by nonlinear regression.

Our experiments showed that photosynthesis and respiration of oak seedlings changed dramatically throughout leaf expansion of the first flush and did not peak until after full leaf expansion. Moreover, the onset of a third flush of growth restimulated photosynthesis of first flush leaves. The pattern of photosynthesis in second and third flush leaves was similar to first flush leaves in relation to shoot ontogeny. For all flushes, leaf respiration rates were high during leaf expansion and declined to a constant level after full expansion. The observed photosynthetic and respiratory patterns provide a basis for building growth models for northern red oak seedlings; however, additional experimentation will be required to understand the physiological events behind the observed patterns.

CAN OAK SEEDLING QUALITY BE QUANTIFIED BY LATERAL ROOT NUMBER?

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Recent research suggested that it might be possible to quantify seedling quality by lateral root characteristics. Initially, we found that approximately 35 percent of all sweetgum (Liquidambar styraciflua L.) seedlings produced in the nursery had fewer than four permanent lateral roots. Sweetgum seedlings with fewer than four lateral roots had significantly poorer survival and growth after 3 years than those with six or more lateral roots. The aboveground seedling biomass could be readily altered by various treatments; however, the frequency distribution of lateral root numbers remained relatively constant.

Using ten half-sib seedlots of northern red oak (Quercus rubra L.), essentially the same frequency distribution of lateral root numbers was found as in sweetgum. Northern red oak seedlings with 12 or more lateral roots were rated the best. Depending on the seedlot, these seedlings represented from 5 to 26 percent of the total seedling population. Seedlings with fewer than seven lateral roots were judged the poorest and represented from 26 to 68 percent of the seedling population.

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ROOT REGENERATION IN NORTHERN RED OAK SEEDLINGS

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Two experiments were conducted investigating budbreak, shoot elongation, and root regeneration of 3-0 northern red oak (*Quercus rubra* L.) seedlings in root observation boxes under greenhouse conditions. The first experiment compared three treatments-- (1) 5 second root dips in 1,000 ppm potassium salt of indolebutyric acid (K-IBA), (2) inserting auxin impregnated toothpicks (soaked for 24 hours in 1,000 ppm K-IBA) into taproot, and (3) untreated seedlings. Auxin treatment did not effect budbreak, rate of shoot extension, or leaf area of first flush relative to untreated seedlings. The auxin-toothpick treatment increased leaf area in the second flush relative to the untreated seedlings. First root regeneration in auxin treated seedlings occurred 4 to 8 days after first root regeneration in untreated seedlings. Root elongation rates of auxin treated seedlings were also slower. Root regeneration occurred first from cut surfaces of small diameter pruned lateral roots and 28 days later from the cut surface of the primary root. Budbreak occurred 14 days before first root regeneration; however, the second flush occurred after the second pulse of root regeneration.

In the second experiment, dormant 3-0 northern red oak seedlings were given a 3 second root dip in 20 millimolar solutions of either K-IBA, indole-3-butyric acid (IBA), N-phenyl indole-3-butyramide (NP-IBA), phenyl indole-3-thiobutyrate (P-ITB), or phenyl indole-3-butyrate (P-IBA). Seedlings dipped in water or 95 percent ethanol served as controls. Fifty-six days after treatment, seedlings treated with NP-IBA and P-ITB regenerated up to 3 times more roots than did ethanol treated control seedlings (48.7, 40.0, and 14.3 roots per seedling, respectively). Seedlings treated with NP-IBA and P-ITB had smaller leaves than K-IBA and IBA treated seedlings. Seedlings treated with NP-IBA had more leaves than K-IBA and IBA treated seedlings (155.3, 59.0, and 53.3 leaves per seedlings, respectively); however, leaf surface areas were similar. Seedlings treated with P-ITB had a similar number of leaves as seedlings treated with K-IBA and IBA; however, P-ITB treatment reduced total leaf area.

IN VITRO MICROPROPAGATION OF WHITE OAK

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Dormant buds and newly emergent shoot tips of mature white oak (*Quercus alba* L.) could not be surface-sterilized without killing the explants; however, 68 percent of shoot tips taken from greenhouse-grown seedlings could be surface-sterilized and acclimatized on woody plant medium. After 4 to 8 weeks in culture, 70 percent of apparently sterile cultures showed contamination by a slow-growing, white bacterium believed to be an internal contaminant. Axillary shoot proliferation and elongation were better on woody plant medium than on either Murashige and Skoog's or Driver and Kuniyuki's medium. No differences in axillary shoot proliferation were observed with 6-benzylaminopurine (BAP) concentrations ranging from 0.1 to 20 ppm. The addition of indole-3-butyric acid (IBA) at 0.002 and 0.1 ppm had no effect on axillary shoot proliferation or elongation.

Axillary shoot proliferation and elongation differed among half-sib progeny in several experiments; however, no interaction with medium, BAP, or IBA levels was found. After 8 weeks in culture, the number of elongating axillary shoots ranged from 0.2 to 1.9 and the length of the longest axillary shoot ranged from 2 to 11 mm among 10 half-sib progenies. Of the 67 uncontaminated cultures that initiated new growth and were tranferred to new medium biweekly, more than 60 percent died within 10 months.

We failed to root newly emergent, surface-sterilized shoots from greenhouse-grown seedlings with various combinations of sterile media, IBA, and the fungus *Pisolithus tinctorius*. Subsequent rooting trials with 70 microshoots taken from 10-month-old cultures (ramets of five ortets) and treated with IBA quick dips resulted in 11 rooted plantlets. Rooting occurred at five IBA concentrations ranging from 0.2 to 20.0 ppm.

PRODUCTION OF NURSERY GROWN NORTHERN RED OAK WITH *PISOLITHUS TINCTORIUS*

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The influence of the ectomycorrhizal fungus *Pisolithus tinctorius* (Pers.) Cohen and Couch (*Pt*) on the production of 1-0 northern red oak (*Quercus rubra* L.) seedlings was studied for 3 years. Inoculation of nursery beds after seedling emergence with vermiculite medium containing vegetative mycelium of *Pt* at 2.25 liter per square meter increased seedling height and diameter all three years and increased the number of salable seedlings in two of the three years. The number of seedlings in the larger size classes (height > 40 cm, stem diameter > 9 mm) and seedling root dry weight (principally the lateral roots) were increased by *Pt* inoculation all three years.

Nursery bed inoculation influenced the mycorrhizal species found on the seedling roots in mid-November, but not the percent of infected lateral roots. The high percent of *Pt* on the primary lateral roots in the inoculated plots (65 to 80 percent) suggests that *Pt* can successfully complete with indigenous fungi. In the inoculated plots the percent of primary lateral roots infected with *Pt* was significantly correlated in all three years with stem diameter (r = 0.55 to 0.71) and lateral root dry weight (r = 0.65 to 0.73) and in one of three years with methanol extractable carbohydrates (year 1, r = 0.65), stem height (year 2, r = 0.69), and total seedling dry weight (year 2, r = 0.71).

ESTIMATING ACORN PRODUCTION OF INDIVIDUAL OAK TREES

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Reliable information is needed on the variation in seed production among individual trees in oak regeneration and mast production research. In the past, visual estimates (counts) before acorn fall or acorn traps have been used, but it is not known how reliable such estimates are. In 1962, total acorn counts and the location of each acorn beneath three mature cherrybark (*Quercus falcata* var. *pagodaefolia* Ell.) oaks were determined. Crown perimeter and location of each acorn were analyzed by plotting them on paper and then sampled by using overlays of different sized and shaped sampling units. It was concluded in an unpublished file report that 61 to 767 samples per tree were needed to estimate the actual population within 10 percent and that 8 to 93 percent of the area needed to be sampled.

We propose to reanalyze this data, which consists of more than 12,000 acorn locations, to determine the spatial distribution of the acorns and to test if it differs from a random distribution. If so, we will attempt to characterize the type of distribution that exists. We will also retest the sampling variables including sampling unit size and shape, distribution of sampling units, and sampling intensity. Results will be compared to the known population means, and sampling variance will be examined to determine at what intensity it becomes stable so that sampling effectiveness and efficiency can be calculated.

ASIATIC OAK WEEVIL IN MISSOURI'S OAK-HICKORY FORESTS

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The lack of natural oak regeneration in the central and eastern hardwood forests is a serious problem. Currently research is underway to study the impact of the Asiatic oak weevil (*Cyrtepistomus castaneus* (Roelofs)) on oak reproduction in Missouri's oak-hickory forests. Study objectives included assessing the temporal and spatial distribution of emerging adult Asiatic oak weevils and investigating host acceptability of feeding adult weevils. Between June and September of 1985, we monitored adult weevil emergence from the soil using 160 emergence traps in eight trapping areas. Peak emergence occurred during the month of July. Aggregation within trapping areas was also observed.

Newly emerged adult weevils collected from emergence traps were introduced into feeding arenas using paired comparisons of feeding on leaves of seven hardwood species. After 24 hours, the leaf area lost to feeding was measured with a portable leaf area meter. White oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), and black oak (*Q. velutina* Lam.) were the preferred hosts. Sugar maple (*Acer saccharum* Marsh.) was an acceptable host when oaks were not present. Hickory (*Carya* spp.), dogwood (*Cornus florida* L.), and sassafras (*Sassafras albidum* (Nutt.) Ness) were not acceptable hosts because no feeding occurred on them. The results indicate that Asiatic oak weevil perfers the foliage of oaks over that of other hardwoods.

INSECTS AFFECTING OAK SEEDLING ESTABLISHMENT

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Research on insects affecting acorns has revealed that 60 to 98 percent of germinating acorns in plots in southern Ohio were destroyed by insects considered to be minor pests. In addition, several "new" species were linked to oak seedling mortality in nursery and forest sites. Future research will concentrate on determining the life histories and impact of these insects.

REGENERATION OF BOTTOMLAND HARDWOODS

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The effects of residual stems on the natural regeneration of bottomland hardwood stands were evaluated on Coastal Plain branch bottoms, wet flats, and muck swamps. Residual control treatments included (1) mechanical (shear or saw), (2) chemical (injection), and (3) control or no treatment. Stocking, origin, and growth of reproduction were evaluated 1 and 5 years after treatment. Although results differed among sites, the mechanical and chemical treatments usually caused a delay in regeneration stocking. After 1 year, both the mechanical and chemical treatments tended to have fewer stems than the control. After 5 years, however, mechanical and chemical treatments had equal or greater stocking than the control. The mechanical treatment resulted in the greatest height growth of all hardwoods in year 1 and year 5.

The oak regeneration showed a pattern similar to the overall response. Oak establishment after 1 year was lower for both the mechanical and chemical treatments than the control. Oak establishment between years 1 and 5 for both the mechanical and chemical treatments exceeded the control. After 5 years, the chemical treatment results in the most oak regeneration, especially on the muck swamp and branch bottom sites. The mechanical treatment resulted in the greatest height growth for the oaks after year 1 only.

EFFECTS OF A NITRIFICATION INHIBITOR AND NITROGEN FERTILIZERS ON WHITE OAK ESTABLISHMENT

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White oak (*Quercus alba* L.) seedlings germinated from seed collected under a single tree were planted on an old field site in southern Illinois that previously had a tall fescue (*Festuca arundinaceae* Schreb.) cover. Urea, potassium nitrate, ammonium nitrate, or calcium nitrate was broadcasted alone or with the nitrification inhibitor N-Serve (2-chloro-6-[trichloromethyl]pyrimidine) and raked into the upper soil surface after preplant cultivation. Fertilizers were applied at 211 kg/ha elemental nitrogen, and N-Serve was applied at 1.5 kg/ha. Treatments also included unfertilized controls with and without N-Serve. Fertilizer and N-Serve were reapplied in the spring of the second year. Weeds were controlled by applying herbicides and by hoeing for 3 years.

Survival after 3 years was 62 and 52 percent with and without N-Serve, respectively, across all fertilizer treatments. Plots fertilized with potassium nitrate had the highest survival (81 percent); in plots fertilized with urea, ammonia nitrate, and calcium nitrate had lower survival rates than the unfertilized controls (67 percent). Trees in the unfertilized controls with N-Serve were 49 percent taller and 29 percent larger in basal stem diameter than trees without N-Serve. Seedling growth in response to fertilizers was as follows: potassium nitrate > calcium nitrate > urea > control > ammonium nitrate.

Percent foliar nitrogen, phosphorus, and potassium during the first growing season were higher in trees receiving N-Serve than those without N-Serve; however, only foliar phosphorus was significantly higher. Percent foliar calcium and magnesium were only slightly affected by the N-Serve. Only percent foliar nitrogen was still higher in the trees receiving N-Serve than in those without N-Serve during the third growing season (3.3 and 2.4 percent, respectively). Significant interactions between the fertilizers and the N-Serve were observed only during the first growing season.

ESTABLISHMENT AND GROWTH OF OAKS ON MINED LANDS

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Oak seed or seedlings were planted each autumn and spring over a five-year period on either unmined old fields, ungraded minesoil, graded only minespoil, or graded minespoil with topsoil replaced. Oak species tested included white oak (Quercus alba L.), bur oak (Q. macrocarpa Michx.), chestnut oak (Q. prinus L.), northern red oak (Q. rubra L.), black oak (Q. velutina Lam.), pin oak (Q. palustris Muenchh.), Shumard oak (Q. shumardii Buckl.), and shingle oak (Q. imbricaria Michx.). The oaks were seeded or planted each autumn or spring depending on availability of acorns or nursery stock; however, as the study progressed we increasingly used seed in the autumn and dormant seedlings in the spring. Replicated plots on the four neighboring sites consisted of 50-tree rows of each species on a 2.5 x 2.5 m spacing. During the last three years of the study, we sprayed a Roundup and Princep mixture around each seed spot or seedling to control the herbaceous competition and reduce rodent damage.

Federal and state regulations now require the replacement of topsoil and establishment of an herbaceous cover to control erosion. These practices result in compacted graded lands unsuitable for establishing most hardwoods. Oaks are among the best species to establish on compacted, graded minespoil. In general, white, bur, chestnut, northern red, and shumard oak performed better than black, pin, and shingle oak. The latter three oak species frequently naturally invade pine or other tree covers on stripmines. Pin oak was among the tallest of the three-year-old trees. Future plans are to continue comparing establishment and growth of hardwoods, including oaks, on several types of sites and in different rooting media to identify the physical limitations to root development.

A PRESCRIPTION FOR PLANTING NORTHERN RED OAK

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A four-step prescription has been developed for planting northern red oak (*Quercus rubra* L.) on forest sites in Missouri. The prescription calls for: (1) controlling undesirable woody understory vegetation with a herbicide before planting, (2) creating a shelterwood overstory at 60 percent stocking, (3) underplanting 2+0 undercut seedlings or 1+1 transplants with clipped tops and basal stem diameters that average about 1/2 inch, and (4) removing the shelterwood three growing seasons after planting. If this prescription is applied, about half of the planted trees should be competitive 2 years after shelterwood removal. Preliminary cost estimates for planting and site preparation range from 200 to 400 dollars per acre depending on numbers of seedlings planted per acre.

ROOT REGENERATION AND GROWTH OF NORTHERN RED OAK SEEDLINGS TREATED WITH HORMONES

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Previous research has shown that endogenous auxins and cytokinins increase in root tissues during root regeneration of northern red oak (*Quercus rubra* L.) seedlings. Furthermore, preplant application of indoleacetic acid (IAA) and kinetin to roots of 1-0 seedlings greatly increases root regeneration in greenhouse studies. In subsequent experiments the following three methods of applying IAA-kinetin hormone mixtures to roots of 1-0 northern red oak seedlings were tested: (1) soak roots in aqueous hormone solution for 24 hours, (2) apply a vacuum for 4 hours during root soak to increase penetration of hormone solution into roots, (3) dip roots into a hormone-starch polyacrylonitrile gel (Super slurper) solution. Part of the seedlings from each hormone treatment were planted in a greenhouse to determine their root regeneration potential. Half of the remaining seedlings were outplanted on a weedy site (only mowed infrequently) and the other half on a site about 200 yards away that was clean cultivated on a regular basis (weed-free). Seedling height and stem dry weight were determined after two growing seasons.

Root regeneration and leaf weight of seedlings in all hormone treatments except starch gel were significantly greater than for untreated seedlings in the greenhouse study. Similarly, all hormone treatments except starch gel significantly increased seedling height and stem weight on the weed-free site. Maximum stem growth resulted from a 4 hour vacuum infiltration with 200 ppm IAA and 0.1 ppm kinetin solution. Seedlings for this treatment on the weed-free site averaged 33.4 g stem dry weight compared to only 13.9 g for untreated seedlings. Stem dry weight of seedlings on the weedy site averaged only 10 percent of dry weight of seedlings on the weed-free site and preplant hormone treatments were without benefits.

Future research will include determining variability in root regeneration potential among families and/or seed sources to applied hormones. Several "new" root promoting compounds such as phenyl-modified auxins and a non-hormone willow extract will also be tested.

SPRAY APPLICATION OF INDOLEBUTYRIC ACID ENHANCES OAK ROOT REGENERATION

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Spray treatments of indolebutyric acid (IBA) on roots of 2-0 seedlings of white oak (Quercus alba L.) and northern red oak (Q. rubra L.) were investigated to test for differences in seedling growth and root regeneration. Concentrations of 0, 1,000, 3,000, 5,000, and 7,000 ppm IBA in 20 percent ethanol solutions were tested. Lateral root number, tap root length, and root dry weight were evaluated after one growing season and total length of shoot growth was measured after two growing seasons.

White oak seedlings treated with 5,000 ppm IBA averaged 43 secondary roots and 48 cm of new shoot growth per plant compared to only 35 secondary roots and 35 cm of shoot growth for seedlings without IBA. Seedlings treated with 7,000 ppm IBA averaged 49 roots secondary roots and 45 cm of shoot growth; however, root dry weight was decreased. For white oak seedlings, tap root length and root dry weight were unaffected by all other treatments.

Northern red oak seedlings treated with 3,000, 5,000, and 7,000 ppm IBA had increased numbers of secondary roots, but no corresponding increase in shoot growth. Seedlings which received 7,000 ppm IBA averaged 43 regenerated roots compared to only 24 for the seedlings without IBA. Shoot growth was significanty increased by 1,000 ppm IBA without an increase in root numbers or dry weight.

EARLY GROWTH OF UNDERPLANTED BOTTOMLAND HARDWOODS

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Two studies were designed to evaluate the potential of underplanting hardwood seedlings for enhancing regeneration of desirable bottomland tree species. The first study involved partial overstory removal and subsequent underplanting of five bottomland tree species on three sites in southeastern Louisiana. Survival after the second growing season was 45, 59, 77, 82, 88, and 98 percent for sweetgum (*Liquidambar styraciflua* L.), cow oak (*Quercus michauxii* Nutt.), Nuttall oak (*Q. nuttalli* Palmer), green ash (*Fraxinus pennsylvanica* Marsh.), rooted green ash cuttings, and baldcypress (*Taxodium distichum* (L.) Rich), repectively. Mean height growth for the second growing season ranged from 9.3 to 21.5 cm. Initial seedling quality affected early growth and survival of all species; however, local site conditions also influenced the survival of cow oak and sweetgum.

In the second study, green ash, baldcypress, Nuttall oak, pecan (*Carya illinoensis* (Wangenh.) K. Koch), and water oak (*Q. nigra* L.) were underplanted in an over-mature cottonwood-willow stand located in the Atchafalaya basin in South Central Louisiana. First-year survival ranged from 88 to 99 percent. Mean height growth from seedlings not clipped off by animals was 8.5, 9.3, 11.0, 17.1, and 23.4 cm for baldcypress, water oak, pecan, Nuttall oak, and green ash, respectively.

GROWTH OF FOUR BOTTOMLAND OAK SPECIES PLANTED AT FIVE SPACINGS IN AN ARKANSAS STREAM BOTTOM

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Seedlings of water oak (*Quercus nigra* L.), Nuttall oak (*Q. nuttallii* Palmer), cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) swamp chestnut oak (*Q. michauxii* Nutt.) and four bottomland hardwood species were planted at five different spacings in a minor stream bottom in southeastern Arkansas. Each plot consisted of 169 trees planted in rectangular grids of 13 by 13 rows on 2 x 8, 3 x 8, 4 x 8, 8 x 8, and 12 x 12 foot spacings. The plantation was cultivated only during the first growing season.

After 8 years, survival averaged 70 to 80 percent for all the oaks. Water oak had the best growth and swamp chestnut had the poorest. Nuttall oak and cherrybark oak grew only slightly slower than water oak. Average heights ranged from 10 feet for swamp chestnut to over 21 feet for water oak. The oaks were 2 to 4 feet taller at the wider spacings than at the more narrow spacings. Diameter growth averaged 1/10- to 1/3-inch per year and, except for swamp chestnut oak, generally increased as spacing increased.

Bolewood, branches, and bark comprised 40 to 50, 30 to 40, and 15 to 20 percent, respectively, of the total tree dry weight. Bolewood weight tended to decrease as a proportion of total weight as the spacing increased, while the percentage in branches increased. Percentage bark was not related to spacing. Initially, leaves made up a high proportion of the total weight; however, the proportion of total weight had stabilized to around 10 to 15 percent after 8 years. Greatest biomass production was in water oak, followed by Nuttall, cherrybark, and swamp chestnut oak. Biomass production per acre was about three times higher at the 2 x 8-foot spacing than at the 12 x 12-foot spacing. Highest green weight production (130,000 pounds per acre through age 8) was in the 3 x 8-foot spacing of water oak.

U.S. Department of Agriculture, Forest Service.

1988. Van Sambeek, J. W.; Rink, George; Johnson, Paul S., eds. Third workshop on seedling physiology and growth problems in oak plantings, proceedings abstracts; 1986 February 12-13; Carbondale, IL. Gen. Tech. Rep. NC-121. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 19 p.

Research results and ongoing research activities in oak plantings and related physiology and genetic studies are described in 19 abstracts.

KEY WORDS: Plantations, propagation, regeneration.

FINDING OUT AND TELLING

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it--in short, "finding out and telling." As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL
FOREST
EXPERIMENT STATION

United States Department of Agriculture

Forest Service

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Integrating Forest Management for Wildlife and Fish

Each contributor submitted camera copy and is responsible for the accuracy and style of his or her paper.

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INTEGRATING FOREST MANAGEMENT FOR WILDLIFE AND FISH

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FOREWORD

People have always expected bountiful resources from their forested land. Today, the increasing demand for fish and wildlife is being reflected in forest resource management. On National Forests, many acres now are being managed primarily for fish and wildlife. To meet these management goals as well as those related to more traditional forest products, rich, diverse forest ecosystems are needed.

The shift to biotic diversity as a major criterion for good land management challenges us all. We must learn to plan habitat management proactively, not reactively. Integrated resource management addresses a richer set of purposes. Biologists and foresters must work as a team and increase their sense of partnership. The keys are integration, leadership, and creativity. The presentations in this session represent innovative approaches to integrated resource management and economic values. They offer ideas on how biologists can join foresters in leading the way.

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INTEGRATED RESOURCE MANAGEMENT - MAKING IT WORK ON THE GROUND

JOEL D. HOLTROP, Hiawatha National Forest Rapid River, Michigan

Presented at the SAF National Convention held in Minneapolis on October 20, 1987

INTRODUCTION

Integrated Resource Management is considering and planning for all resources in the same area at the same time, using an interdisciplinary approach. It is how the National Forest Plans were developed, and now how they are being implemented.

Integrated Resource Management (IRM) can be explained with buzz words and concepts, such as "Interdisciplinary Teams", "Management Areas", "Opportunity Areas", and "Desired Future Condition". But making IRM work on the ground requires more than words and concepts. It requires things like a champion for resources like fisheries, wildlife, and endangered plants. It requires real, meaningful public participation. It requires cooperative relationships, well-articulated objectives for all resources, and more.

Not that the words and concepts associated with IRM are not important. It is essential to have a common approach and consistent terminology. Basic concepts and an understanding of the value of an integrated approach are essential. However, I will concentrate on some of the other items necessary to make IRM work on the ground.

INTEGRATED RESOURCE MANAGEMENT

First of all, though, let me lay the ground work of what I mean by Integrated Resource Management. It is the Forest Service Eastern Region's approach to implementing our Forest Plans. The Forest Plans were developed by considering all the resources of the Forest at the same time using an interdisciplinary team. That is, the Forest Plans are integrated resource plans. Now, as we implement the Plans, as we get more site and project specific, we must continue to do so in an integrated fashion, to stay consistent with the Plan.

The IRM approach involves identifying and analyzing 5,000 to 20,000 acre sections of the Forest called Opportunity Areas. These Opportunity Areas are analyzed by an interdisciplinary team that considers all the resource opportunities and concerns of the area at the same time. Based on Forest Plan direction, a long-term Desired Future Condition forms the basis for what projects need to occur during the next 10 years to move us toward that desired condition. The projects have been planned at the same time for the Opportunity Area, so integration of the various projects occurs. Integration like closing roads by planting wildlife supporting shrubs. And cutting aspen to encourage beaver activity to create wetland habitat, and locating a timber skid trail to provide access for a future fisheries project. This helps insure efficiency and avoids conflicts between projects.

In the past, we had individual plans for every resource. For instance, there were river plans for watershed and fisheries improvement, timber plans, recreation plans, and wildlife plans. Each of these tended to head in its own direction, with the result being conflict and inefficiency. Integrated Resource Management brings all of these together as one integrated plan.

We have some common concepts and terminology in IRM, and good professionals very capable of implementing resource technology. Now what does it take to make Integrated Resource Management really work on the ground? Based on experiences with things that have been successful, and others that have not been as successful, takes:

Public participation
A Champion for key resources
Objectives for all resources
An interdisciplinary team attitude
Cooperative relationships

Now I will discuss each of these items.

PUBLIC PARTICIPATION

Making IRM work on the ground requires real, meaningful public participation. For truly integrated resource management to be implemented, all kinds of resource projects must occur. Not only popular projects, but also controversial ones. Public participation identifies sensitive issues, concerns, and opportunities. If done well, it insures the public will not be surprised. It helps develop public support for the integrated projects. And it provides a basis for better understanding of resource management. All this adds up to a better decision, as well as a better chance of being able to implement all of the integrated resource projects incorporated in that decision.

There are a few pitfalls to avoid in public participation. The first is seeking public input too late in the decision process. Get public participation throughout the decision making process Many Ranger Districts in the Eastern Region have even used members of the public on their interdisciplinary teams.

The second pitfall to avoid is not talking to a wide enough range of publics. It may not be easy to get any public input, and this varies by geographic area and level of controversy, but generally it is easier to get local input, more difficult to get regional or national publics involved. It also tends to be easier to get input from the vocal extremes, but not the less vocal "middle of the road" publics.

The third pitfall is a tendency to try to sneak by sleeping dogs. There is a temptation to try to implement projects or plans before affected publics know or understand all the effects. In the long run, this strategy will not work.

We need the public's consent to manage the National Forests. Informed consent of the public is stable. It legitimizes what we do. It wins supporters for good resource management. Uninformed consent, on the other hand, is a time-bomb, threatening everything we do. It will lead to lack of trust, when unexpected negative effects occur. So, address your critics and potential critics throughout the public participation process.

As time allows, there is nothing like the personal touch. Go to an affected public's home or office, and one on one ask them their opinion on what should be done in a particular area. I have found people to be flattered, even honored by the opportunity to express their views in this context. These people have been able to understand and provide quality input on our 5,000 to 20,000 acre Opportunity Area analyses. Some have mentioned their relative comfort with input at this stage in relation to the overwhelming size and complexity of providing input into the Forest Plan.

Real, meaningful public participation leads to better, more informed decisions, and it produces public support so integrated resource management can be implemented on the ground.

A CHAMPION FOR KEY RESOURCES

For the management of an area to be truly integrated, the key resources need to be fully considered. This may seem to be as easy as having the appropriate resource specialist serving on the interdisciplinary team for that area. That certainly is a major step in the right direction.

But I want to highlight that role more than that. There needs to be a strong advocate for key resources that have historically received less attention. Someone who knows the resource well. Someone who can and will uphold the needs of that resource. Someone I would call a champion for that resource.

Without a champion for these resources, they will fall by the way-side in the push for other things. Without a champion, they will not attain their rightful level of prominence in the integrated resource management of an area.

Let me illustrate with a couple of examples. Rare or sensitive plants are often overlooked in resource management. It takes a champion for these plants - for orchids, prairie grasses, ferns, whatever - to see they are adequately considered. On the Rapid River Ranger District we have a very few remnants of the big grass prairie species. An individual with botanical ability recognized the prairie grass species, recognized the potential significance of our remnant stands of these species, and articulated his knowledge and foresight. Thanks to that champion, where appropriate we have integrated the protection and expansion of native prairie grasses into out management scheme.

Another example of a champion making IRM work is the Forest Service fisheries initiative: Rise To The Future. I am proud to say the Hiawatha National Forest is one of the nation's leaders in fish habitat management and restoration. The reason for the Hiawatha's prominence is largely due to the tenacity of the Forest's first fisheries biologist. He recognized the tremendous potential for fisheries on the forest, and he championed the cause of fisheries until it is now fully integrated into our Forest Plan.

The entire fisheries initiative is the result of champions in all levels of the Forest Service and other groups. Its future depends on champions continuing to labor at all organizational levels.

OBJECTIVES FOR ALL RESOURCES

Integration implies all resources are considered at the same time in one area. For integration to really occur, all key resources need to have enhancement or improvement objectives, not just mitigation objectives.

A resource with clear objectives for outputs or improvement that relate to the Desired Future Condition is easily incorporated into an interdisciplinary analysis. A resource without stated objectives for the area being analyzed is in danger of only being considered in the realm of mitigation.

An objective like "improve fish habitat" is not precise enough when putting IRM to work in an Opportunity Area. If possible, the objectives should include things like desired species and amount of increased productivity. With objectives like that for all key resources, true integrated resource management can work on the ground. If only some of the key resources have well-stated, clear objectives, true integration is handicapped at the implementation phase.

AN INTERDISCIPLINARY TEAM ATTITUDE

The interdisciplinary team needs to have an interdisciplinary attitude to make IRM work on the ground. The team needs to be more than a collection of people representing different disciplines. The team members need to have a mind-set that encourages integrated resource management.

This can be difficult to attain. Selection of team members must consider personalities, leadership, and cooperativeness, as well as resource specialty.

Often, though, there is little choice in the team's make-up. To develop an interdisciplinary attitude on the team is certainly still possible, but it will not just happen.

The team needs to have the attitude of working toward a common goal. Each team member has personal interests and strengths. Hopefully, some are even champions for a key resource. But in the team concept, the emphasis is a common goal. The team needs to work together, with the common goal being managing the area as best as it can be.

Developing the proper attitude on an interdisciplinary team to make IRM work requires strong coaching and direction from the line officer. In the Forest Service, that means the District Ranger. Spend time with the team, emphasizing the need to be integrated.

A team in which all the members work on the entire integrated solution, not just their own resource, has what I call an interdisciplinary team attitude. That team will make IRM work on the ground.

COOPERATIVE RELATIONSHIPS

This might be the most powerful aspect of making integrated resource management work. Cooperative relationships are absolutely essential for they provide financial support, and form a basis of support for integrated resource management

Particularly in fish and wildlife habitat management, a close cooperative relationship with the state agency is essential. On the Hiawatha National Forest, we enjoy an excellent partner[illegible] with the Michigan Department of Natural Resources. That partnership is a key ingredient in our successful fisheries restoration program.

But let me discuss cooperative relationships with other groups. Groups like Trout Unlimited, Ruffed Grouse Society, Ducks Unlimited, and Wildlife Unlimited. Groups like these are providing the funds necessary to make integrated resource management work on the ground. The Challenge Grant Program is allowing us to multiply their contributions with matching allocations from Congress. Another important spin-off of these partnerships is they provide us with contacts, supporters, and friends in key places. So the financial help and the grass-roots support allows us to make IRM work.

Let me tell you a little about an example, Wildlife Unlimited of Delta County. This group raises well over $50,000 each year to put directly into fish and wildlife projects in Delta County, Michigan. We are talking here about a county whose population is around 39,000 people. In 1986, Wildlife Unlimited funded about $30,000 for projects on the Rapid River Ranger District. What a pleasure it is to do that work, especially for such an appreciative public.

Let me discuss building a relationship with a group like Wildlife Unlimited or Ducks Unlimited. Five things I have found to be effective are:

1. Quality project proposals. When the call comes from an organization for project proposals, be ready to respond with well-planned, documented proposals. The IRM Opportunity Area analysis facilitates this by identifying project sets for the next 10 years. Take the time to document the project proposal in an attractive manner.

2. Be involved in the organization. Be a member, serve on the advisory board, or on a planning committee. It not only makes excellent contacts for funding, it makes excellent contacts with people who really care about the management of their forest resources. And it is enjoyable, too.

3. Provide feedback to the organization on projects completed, even without them asking for it.

4. Publicity for the organization. Always credit them when talking to the media. Never forget.

5. Thank them. I sent Wildlife Unlimited a copy of the U.S. House of Representatives' Committee Report on the Challenge Grant Program that listed organizations involved. I thanked Wildlife Unlimited for their support, and congratulated them on being recognized by the US Congress. A simple little thing, but it made one local organization very proud.

I can not emphasize enough how much cooperative relationships have to do with making integrated resource management work on the ground.

CONCLUSION

The overall results of integrated resource management are an appropriate balance of resource projects and outputs from a piece of land. The public better understands and supports the resource management and local economies benefit. There are multiple benefits, and efficiently coordinated projects.

It takes some effort to make it work on the ground. Perhaps a different kind of effort than we have made before. It is an effort that really embodies all of the basic principles underlaying the Eastern Region's IRM approach.

We need to recognize people as our most important resource, because we need them to be champions for their resource and to set resource objectives.

We must be good neighbors, to get real, meaningful public participation, and to develop cooperative relationships.

Finally, we need to work together as a team, so we have a true interdisciplinary team attitude, to result in integrated resource management.

Integrated Resource Management is an attitude, not a process. We have developed it into an approach that can work. But to make IRM really work on the ground, you have to want it to. It has to be your attitude, which will expand to be the attitude of those around you.

Integrated Resource Management Means Management for Fish and Wildlife Too

by Floyd J. Marita, Regional Forester,
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Good afternoon. I'm glad to be here today. There are some exciting things happening in the Eastern Region of the Forest Service and I'm anxious to tell you about them. During this year we have been working together as part of a Pilot Project. We call it Project Spirit. Project spirit is our way of trying better ways of accomplishing our work; looking for new ways to be more efficient. It involves everyone. Our Region thrives on teamwork. Integrated Resource Management, known as IRM, is teamwork in action. Let me tell you how IRM got started.

The Forest Service has been completing the first round of comprehensive land and resource management planning as congressionally mandated by the National Forest Management Act. As the Forest Plans in the Eastern Region were completed, several things became clear. I'm going to talk to you about two of them.

First of all, it was obvious to us that implementing the Forest Plans' goals and objectives would require an effort unlike any previously undertaken anywhere in the Forest Service.

Secondly, the public told us to achieve a better balance in resource management.

The Forest Service has a long history of habitat manmagement. In the Eastern Region, we have 45 wildlife and 8 fisheries biologists. Our annual budget is 4.5 MM. That sounds like a sizeable program until you spread it over:

--17 National Forests
--11 million acres of land
--960,000 acres of lakes, and
--over 13,000 miles of streams

The public's "program balance" message was uppermost in our minds when we confronted Plan implementation. Accordingly, we developed a process to implement Forest Plan goals and objectives in a way which will achieve that balance. We call this process Integrated Resource Management. We think it is a land management approach that can be used anywhere--not just on National Forests. It can be applied equally well to any private or public land where balanced resource management is a goal.

IRM departs from planning and implementing activities by individual resource as is done on nearly all other Federal, State and private lands. It is a systematic way to insure that all resources are taken into account. Let me give you some examples of traditional approaches:

--Opportunities to manage industrial and State Forest lands for recreation, wildlife and fish habitat are usually considered secondarily.

--State fish and wildlife management areas are seldom sources of wood products, even when timber management could directly benefit many wildlife species.

--Park management emphasizes visual quality and general recreation, but seldom employs timber or wildlife habitat to enhance either one.

IRM, in contrast, coordinates all actions, such as the management of timber, recreation, wildlife and fish habitat and visual resources to achieve overall area goals and objectives. With IRM, management of all resources in an area is planned and scheduled over the next decade, using an interdisciplinary approach.

IRM is teamwork with the public:

--Pooling expertise to manage all resources in a planning area to meet public needs.

--Designed to unify people and manage resources in a coordinated manner.

--Each person knows his or her role, what is expected, when to do it.

The result of this team effort is not managing every acre for all interests, but an integration of resource management to achieve true balance in multiple use. We feel good about that.

IRM helps us to look at what we've done and make changes when we need to. Management costs are lower and public benefits are higher because IRM schedules work in a same-time/same-place manner.

IRM employs six simple steps to assure program balance in an area:

1. Units of land, usually 5,000 acres or more, which offer the best opportunities to implement Forest Plan goals and objectives are identified. These land units are called Opportunity Areas.

2. The desired future condition of an Opportunity Area is spatially arranged and integrated project sets meeting Forest Plan direction are identified.

3. Projects are scheduled and budgeted.

4. Projects are designed, considering needs of all resources and values.

5. Projects are executed as designed.

6. Resources and property values are protected and managed. This is how it works:

1. An interdisciplinary team with the needed expertise for the Opportunity Area works through Step 2. They spatially arrange integrated project sets to achieve the desired future condition.

2. Managers then schedule and budget these project sets.

3. Last, individual projects are designed and executed in an integrated manner.

State and other agency fish and wildlife biologists routinely provide consultation and review to National Forest IRM teams. Several State biologists have served as team members and some have taken IRM training given National Forest personnel. Biologists from at least three States have expressed a desire for their agency to adopt IRM or a similar process. I think that says a lot about IRM.

Participation by State biologists serves two purposes:

1. They provide needed expertise when it is not available, in-house.

2. They can do much to insure that wildlife and fish habitat management on National Forests is compatible with the goals of their own agency. Related project work may even be coordinated for greater efficiency.

IRM puts all resources on equal footing. Since management is based upon land capability, wildlife and fisheries become the driving forces in some cases. Where wildlife and fisheries are not primary concerns, they still benefit, because IRM emphasizes taking advantage of habitat improvement opportunities which are coincidental to managing other resources. IRM also emphasizes preventing adverse impacts rather than mitigating them. Potential resource management conflicts are resolved equitably before implementation by the range of expertise integrated into the process. Fewer options are foreclosed to future management.

Further, when this range of expertise concentrates on a land unit, previously unrecognized opportunities emerge. IRM serves as a "discovery" process, improving the quality of land management by considering all opportunities and priorities within the umbrella of the Forest Plan direction. Program balance improves. This point may be best demonstrated by the fisheries resource.

The health of aquatic systems reflects the stability of terrestrial systems. Put another way, simply because water runs downhill, the quality of fish habitat reflects the quality of land management--or the lack of it.

As Edwin Miller, Professor of Forestry at Oklahoma State University, points out in a recent paper, aquatic systems are tightly tied to terrestrial systems for such things as:

1. Food energy.

2. Cover and habitat diversity as provided by large woody debris.

3. Temperature regime.

4. Bank stability.

5. Regulation of nutrient and sediment input.

6. Waterflow regime.

Forest management has the potential to effect all these factors positively or negatively. However, an added consideration makes this list especially important to Forest managers. By nature of their locations, National Forests have an abundance of headwater streams. Small streams, including intermittent or ephemeral waterways, are the most sensitive or vulnerable to the effects of land use. They are the point of maximum interface between the aquatic and terrestrial systems. The health of small headwaters is reflected far downstream.

As we implement our Forest Plans, some examples show how we can address fisheries opportunities:

During road construction/reconstruction, simple guidelines such as bringing the roadbed down to grade well back from stream crossings can significantly reduce sediment input. There are also economical opportunities during reconstruction to re-set culverts which may block fish movement.

Vegetation management prescriptions promoting long-term accrual of dead and down large trees to riparian areas and shorelines enhance fish cover and habitat diversity at no direct cost. Long-term vegetation management can also promote or discourage beaver activity which is undesirable on low-gradient trout streams, but which may be desirable elsewhere.

Timber sales near lakes and streams can be sources of material for log cribs and brushpiles. Whole trees from sale areas can be anchored in littoral zones and stream channels. This avoids risking bank stability by using shoreline trees for fish cover. Trees can be positioned during frozen conditions to avoid disturbing riparian soils.

Direct fish habitat improvement can often be coordinated with other work such as construction of boat ramps, bridges and near-shore campsites. Sometimes the same crews and equipment can be used for both jobs.

All these examples require a high degree of coordination - a true integration of the management skills of fisheries biologists, engineers, transportation planners, wildlife biologists, foresters, and hydrologists. It also means that our partnership with the public involves all of the resources in our organization; our human resources at all levels, including our Older Americans.

Fish are not mobile in the sense that terrestrial wildlife is. We can't shift or extend their local ranges or distribution as we can with many wildlife species. However, we can avoid damaging existing habitat and we can dramatically improve its productivity. Implementing our Forest Plans through IRM is a key element in helping us recognize and take advantage of opportunities to improve or restore fish habitat simply because it forces us to more fully consider the needs of all resources as we work on a given land unit. IRM will not let us simply hit the high points in one land area and move on to the next one. IRM forces land management in the fullest sense of resource stewardship.

In assuring program balance, IRM can turn critics into a support base. Fishermen and hunters constitute the biggest single public lands user group in the U.S. Further, nearly 110 million adult Americans participate in wildlife association activities other than fishing and hunting. These groups have tremendous untapped potential for volunteerism and funding support.

The Eastern Region's 1988 Challenge Grant Program has the potential to bring in over $1,120,000 in outside funding and we are just beginning to market our wildlife and fisheries programs and opportunities.

The program includes projects with national organizations such as Trout Unlimited, The Ruffed Grouse Society, Ducks Unlimited and the Wild Turkey Federation.

Among our partners are state level organizations like the Michigan Steelheaders, the Wisconsin Waterfowler's Association and the Minnesota Deer Hunter's Association.

A particularly gratifying element in the Challenge Grant picture is strong participation by local clubs and organizations like the Island Run Sportsmen's Club and the Clarion Explorer Post, both in Northwest Pennsylvania, and Wildlife Unlimited of Delta County, Michigan.

Of course, our long-term partners, State fish and wildlife agencies, are also strong participants in the Challenge Grant program.

IRM is no different from anyting else in that what you get out of it depends on the effort you put into it. IRM carries some challenges in this regard.

It challenges wildlife and fisheries biologists to channel increased program emphasis into efficient, productive work. To do this, they must acquire inventories, data bases, analytical tools and new habitat improvement technology while continuing to implement sound projects on the ground in response to opportunities already identified.

IRM challenges all professional groups, biologists, foresters, engineers, and recreation managers alike to avoid turfism and participate openly in the IRM process. They must all adopt a wholistic view, answering as many resource management needs as possible in same-time/same-place fashion, recognizing special needs of sensitive resources and user groups.

IRM challenges the public, especially user groups and conservation organizations to participate in the process. Their input can be pivotal. The public is also challenged to participate in the management scenarios they help develop through volunteerism and cooperative funding. Perhaps nothing facilitates volunteerism as well as fish habitat improvement. It closes the public involvement loop as members of the public execute projects resulting from their earlier input to Forest plans.

The need to involve the public in funding natural resource management is gaining recognition. Gordon Guyer, Director of the Michigan Department of Natural Resources made this comment last October - "I think the greatest challenge we face, personally, is habitat; both the acquisition and management of it...We've gotta get people in there from the private sector."

With increasing demands on public lands, there may be no "right" answer to some management issues. Recreational tank driving and warhead testing probably cannot be accommodated by integrated resource management. But our experience with Forest Planning shows that it will provide the best answer to complex management issued because it considers the broadest possible range of opportunities to carry our Plan direction while facilitating the exchange of the other person's perspective, and that's the point natural resource managers must start from in any conflict resolution. Achieving program balance within the context of resource stewardship is what IRM is all about. Wildlife and fisheries resources are among the primary beneficiaries.

Integrated Resource Management means we are all members of a team . . . we all work together. I think that's something to be excited about!

ASPEN MANAGEMENT FOR RUFFED GROUSE[1]

Gordon W. Gullion[2]

ABSTRACT.--The aspens (Populus tremuloides; P. grandidentata) should be considered the primary or basic plant resource supporting ruffed grouse (Bonasa umbellus) populations across more than 95 percent of the latter's continental distribution. The habitat requirements of these forest game birds are best met by different stages in the successional development of aspen stands. The aspens and the ecosystem they dominate best provide for the food and cover needs of these grouse at all seasons of the year. Where these resources are in proper juxtaposition in time and space densities of about 24 breeding pairs of grouse/100 ha (10/100 ac) can be expected. Management of aspen to benefit ruffed grouse consists basically of treating aspen stands in the manner that best perpetuates aspen on the site. The maintenance of this ecosystem was dependent upon fire in the primeval forest and suffers when forests are effectively protected from severe disturbance for more than 40 to 60 years across most of its range. Commercial clearcut logging during the dormant season effectively substitutes for fire if done properly.

INTRODUCTION

The aspens provide the primary habitat resource for ruffed grouse across Canada and the northern United States, or more than 95% of this important game bird's native range (Gullion and Svoboda 1972).

The aspens have the widest geographical distribution of any North American tree, being an important part of the forest composition on more than 172 million ha (425 million acres), or 26% of the forested area north of Mexico (Gullion 1985). Then it is not surprising that ruffed grouse enjoy the widest distribution of any resident game bird on this continent.

At some time during the growth of an aspen stand the highest quality cover or food resources are provided ruffed grouse at some stages in their life history.

Moderate density aspen sapling stands provide the highest quality of cover from fall through the winter and during the breeding season (Gullion 1977), and in summer the best cover for the growing brood (Kubisiak 1978).

The most secure nesting cover is in more open, park-like stands of mature aspen. These older aspen, especially those under some sort of physiological stress, provide the staminate flower buds that are the most valuable winter-long food for these grouse (Svoboda and Gullion 1972).

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[1] A paper presented at the Wildlife and Fish Ecology Working Group Technical Session, 1987 Society of American Foresters Convention. Minneapolis, Minnesota, October 21, 1987. This is Paper No. 2284 of the Miscellaneous Journal Series of the Minnesota Agricultural Experiment Station, reporting research conducted on Minnesota Project No. 83H.

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The forest community or ecosystem that is most valuable to ruffed grouse is a system maintained by periodic catastrophic destruction, followed by secondary succession. This community is composed primarily of shade-intolerant trees and shrubs that regenerate rapidly following destruction by fire or windstorm.

LOGGING SUBSTITUTES FOR NATURAL DISTURBANCE

Clearcut logging produces many of the same ecological benefits, and provides some distinct advantages to mankind that may not result from the natural agents responsible for forest renewal.

Among the obvious advantages is the control over when, where and how extensive the disturbance may be, and usually a product usable by industry is produced.

Currently the harvest of aspen in Minnesota provides more employment, both in the woods and in the mills, than any other forest product. Even though it is less valuable than most other species on a per unit basis, the volume of the aspen harvest makes it Minnesota's most valuable timber crop. The 3.96 million m^3 (1.52 million cords) of pulpwood delivered to mills in 1984 had a value of about 50 million dollars, and more than twice the value of all other species combined (Blyth and Smith 1986; Lothner unpubl. data[3]).

On the other hand, aspen also requires less management effort and expertise than any other Minnesota forest tree. Clearcut harvesting at the proper age and season is usually all that is required to maintain vigorous, fully-stocked stands, ready for harvest every 40 years or so.

LOGGING PROVIDES HIGH QUALITY HABITAT

For ruffed grouse and other wildlife the advantages of regulated harvest are based on the control over age-class distribution, stand dispersal and the size of harvested parcels.

Proper interspersion of age-classes is necessary to assure that food and cover is in the proper spatial relationship, which in turn is determined by the behavior, or more specifically, the preferred mobility of the wildlife to be benefitted.

Based on the locations of the sites selected by the male ruffed grouse for their drumming logs, these birds prefer moderately dense shrub and/or sapling vegetation growth within 100 meters (100 yards) of the mature aspens providing a winter-long food resource. Shrub-sapling densities acceptable for cover range from about 7,000 to 40,000 stems/ha (3,000 to 16,000/stems acre). The lower densities are in relatively pure aspen-hardwood sapling stands; the upper densities in thick hazel (Corylus) or other shrub cover. But in Minnesota, at least, ruffed grouse tend to be most abundant where aspen saplings constitute the highest percentage of the vegetation composition (Gullion 1983).

SCALE OF TREATMENT IMPORTANT

Aspen management for ruffed grouse consists of periodic harvesting of suitably-sized blocks in such a manner that there is old and young aspen in an acceptable juxtaposition throughout the harvest rotation (Gullion 1984).

Ideally this means clearcutting blocks about 4 ha (10 ac) in size, at 10- to 12-year intervals, in a 4-stage rotation around a central point.

Even smaller blocks, 1 ha (2.5 ac) in size are preferable where economic considerations are less important than providing the greatest amount of optimum ruffed grouse habitat.

Other configurations are possible and useful, but none are as easily delineated in the forest nor as satisfactory as a series of square blocks in providing proper spatial relationships at all stages in the rotation.

Current data indicate that benefits to ruffed grouse decline rapidly as the size of the clearcut exceeds the optimum.

Whereas a series of properly spaced 1 ha (2.5 ac) clearcuts will support 4 or 5 pairs of breeding grouse per 16 ha (40 ac), a series of 4 ha (10 ac) clearcuts will probably not support more than 2 pairs per 16 ha (40 ac). If size of the cutting is 8 ha (20 ac) the resulting grouse density is likely to be no more than one pair per 16 ha (40 ac), and as the size of clearcuts increases grouse benefits diminish in almost direct proportion.

The total area cut is less important than the size and interspersion of the individual cutting blocks. An optimum harvesting rotation should take one-quarter of the managed area in each rotation.

I should point out that these observations, based on over 20 years of observations of ruffed grouse response to habitat manipulation on the Mille Lacs Wildlife Area in central Minnesota, provide somewhat lower rates of response than we forecast earlier, based on data from the Cloquet Forestry Center farther north (Gullion 1984).

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[3] Unpublished forest product price data provided by D. C. Lothner, North Central Forest Experiment Station, Duluth, Minnesota.

TIMING OF HARVEST CRITICAL

Since ruffed grouse respond quickest and at highest densities to the best aspen regeneration it is important to harvest at a time and in such a manner that this will occur.

Total removal of all standing aspen down to 2.5 – 5.0 cm (1 to 2 inch) saplings is important to assure dense, even, and rapidly growing sucker regeneration. Cutting during the dormant season when there is maximum storage of carbohydrates in the root system is preferable to harvesting at any other season. But this is not as critical in vigorous aspen stands on good sites as it is for decadent or sparse stands, or on poorer sites.

Post-cutting disturbance or grazing, especially once regeneration has begun sprouting, should be avoided. Virtually all of the regeneration occurs in the first and second season after cutting. Sucker density lost at this time is seldom recovered.

TIMING OF WILDLIFE RESPONSE VARIES

Of all the wildlife benefitting from aspen management ruffed grouse are second to beaver in being most dependent upon it, but are most demanding in their need for proper age class interspersion. On the other hand, these grouse are also one of the last species of wildlife to commence heavy use of this resource.

While deer, beaver, woodcock, snowshoe hares and a number of songbirds begin using cut-over aspen stands within the first or second year of regeneration, these dense sucker stands have to go through one or two natural thinnings before ruffed grouse make heavy use of them. Most aspen sapling stands need to have naturally thinned to one-quarter to one-half initial density before these grouse will use them. The rate at which this occurs depends upon several factors, but it usually means that use does not begin until the aspen is 6- to 12-years old.

On the Mille Lacs Wildlife Area in central Minnesota, on heavier soils and in a warmer climate ruffed grouse usually begin using the aspen saplings 6 to 8 years after harvesting; but at Cloquet on sandier soils and in a colder climate 145 km (90 miles) to the northeast, it is more often 10 to 12 years before the aspen stand develops the characteristics essential to be cover for these birds.

FREQUENT TREATMENT NECESSARY

On the more favorable Mille Lacs sites few stands of aspen regeneration remain acceptable to grouse longer than 15 years after cutting; at Cloquet use continues 20 to 25 years after cutting. The difference lies in the relative rates of natural thinning, and at Mille Lacs, the recovery and increasing dominance of the other hardwoods (ash, maple, birch, basswood, and oak) that have little or no value to these birds.

At Mille Lacs we have found that aspen has remained dominant, and ruffed grouse use has continued several years longer on sites where a northern hardwood forest was uprooted by bulldozing as compared to nearby similar stands that were clearcut (Gullion 1983).

In any event, aspen stands must be treated in a continuing rotation to maintain ruffed grouse cover. When this is done, as one block of cover loses its value to these birds another nearby block harvested 6 to 10 years earlier becomes suitable for their use.

THE FUTURE IS BRIGHT

In closing it appears safe to predict that the current demand for aspen in Minnesota and the widespread acceptance of harvesting guidelines developed as the result of a quarter century of research involving ruffed grouse and aspen management will result in a marked increase in the abundance of this popular game bird in this region. There is every reason to expect that this increased abundance will extend well into the next century as the aspen stands being harvested now develop into prime quality ruffed grouse habitat over the next two decades.

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WOODLAND LANDSCAPING FOR WILDLIFE

Carrol L. Henderson

ABSTRACT -- One comprehensive, ecological approach to the management of wildlife is a holistic strategy termed "Landscaping for Wildlife". Information from wildlife managers, foresters, agricultural extension specialists, horticulturists, botanists, nurserymen, and landscape architects has been collected to assimilate relevant information from their respective disciplines into one useful reference. "Landscaping for Wildlife" includes techniques for managing midwestern wildlife ranging from monarch butterflies to white-tailed deer. Comprehensive principles for landscaping for wildlife will be reviewed with special emphasis on woodlands. Involves the management of 16 components - eight living plant components and eight structural components.

"Landscaping for Wildlife" is a comprehensive, ecological approach to the management of wildlife that treats wildlife in a holistic manner. For the past three years I have collected information from wildlife managers, foresters, agricultural extension specialists, horticulturists, botanists, nurserymen, and landscape architects to assimilate relevant information into one useful reference - a book called "Landscaping for Wildlife". That book is now being printed and should be available from the Minnesota Department of Natural Resources by December 15, 1987. It will be approximately 150 pages long and include a variety of information useful throughout the Midwest.

I would like to share with you some information from the book, especially as it applies to woodland management.

"Landscaping for Wildlife" involves the management of 16 habitat components - eight living plant components and eight structural components: 1) Conifers, 2) Grasses and legumes, 3) Butterfly, bee, and moth plants, 4) Hummingbird plants, 5) Summer plants, 6) Fall plants, 7) Winter plants, 8) Nut and acorn plants, 9) Nest boxes, 10) Snags, 11) Brush piles and rock piles, 12) Cut banks, cliffs, caves, 13) Dust and grit, 14) Salt, 15) Water, and 16) Feeders.

Many landowners in the Midwest own woodlots of 40 to 80 acres for recreational, esthetic, or economic reasons. The first impulse of many of these citizens is to protect their woodland from disturbance, include cutting. However, successful forest management is complex science which frequently requires active manipulation in order to achieve the goals for which the property was purchased. The key to successful management lies in recognizing the features of the woodland upon which a management plan can be designed. An excellent reference for woodlot management is Decker et al (1983).

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[1] A paper presented at the Society of American Foresters Convention held at Minneapolis, MN on October 20, 1987.

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As with other habitats, woodlands must provide food, water, shelter, and space for wildlife. The greater the vegetational diversity, structural diversity, and vertical diversity of the woodland, the greater will be the diversity of the wildlife populations present.

Food is provided by mast-producing trees, snags, fruit-bearing trees and shrubs, browse, buds, grasses, food plots, feeding stations, and salt licks.

Water is provided by ponds, beaver ponds, marshes, swamps, lakes, streams, springs, and gravel pits.

Shelter in woodlands is provided by conifer stands, tree cavities, brush and rock piles, thickets, unmowed grassy areas, caves, snags, south-facing slopes, riparian vegetation, ant mounds, cut banks, unbroken forest tracts, old growth, logs, old building sites, bridges, and nest boxes. (Abandoned ant mounds are used as wintering sites by small garter snakes, smooth green snakes, and red-bellied snakes). The DNR Private Forest Management (PFM) Program Specialist can identify your forest types and develop a plan for managing both timber and wildlife on your land. Contact your local DNR forester for more details.

Riparian Zones

A riparian zone is the area of vegetation adjacent to wetland or watering habitats. Riparian vegetation typically grows well in wet or moist soils and may include emergent aquatics, sedges, rushes, shrubs, deciduous trees, and conifers. Riparian zones support an abundance of plant and animal life and are an important source of diversity in forests (Thomas et al 1970).

Among birds found in riparian zones are the barred owl, great blue heron, broad-winged hawk, spotted sandpiper, pileated woodpecker, belted kingfisher, red-shouldered hawk, wood duck, common goldeneye and hooded merganser. Typical mammals are the black bear, fisher, otter, mink, beaver, raccoon, muskrat. Reptiles and amphibians typical of riparian zones are wood turtles, Blanding's turtles, leopard frogs and snapping turtles. These areas are especially important for cavity-nesting species.

Buffer zones 200 feet wide should be left around all wetlands over one acre in size and along streams and rivers. Buffer zones 100 feet wide should be left around wetlands smaller than one acre. Grasslands adjacent to wetlands should not be used as sites for dumping logging slash. Salvage wood cutting and fuelwood cutting should not be done in riparian zones because these trees, particularly dead trees and hollow trees, are so important for wildlife. If woodcutting is necessary, single tree or small group selection is the recommended harvesting method. Riparian zones should be considered for preservation as "old growth" areas. Trail and road construction should be minimized in riparian areas because of the problems associated with increased erosion from roadways and human disturbances. Grazing should be minimized in riparian zones.

Wetlands

Wetlands are a vital part of a forest community — springs, small ponds, beaver ponds, lakes, streams, rivers, and wet lowlands. They should be preserved. There may be opportunities for creation or enhancement of wetlands where the topography and soils allow. Preservation of riparian zones as buffer strips is an integral part of a wetland preservation plan. The DNR area wildlife manager should be consulted for recommendations about wetland management in forest lands.

Old Growth

"Old growth" is comprised of forest areas that are generally one and a half times the age of traditional forest harvesting.

Wildlife species that benefit from the presence of old growth are the pileated woodpecker, gray treefrog, water shrew, heather vole, red-shouldered hawk, chorus frog, merlin, pine marten, yellow-billed cuckoo, barred owl, northern goshawk, fisher, lynx, wood warblers, and bald eagle. On the Chippewa National Forest, 145 wildlife species use old growth stands during at least some part of their life. The Chippewa National Forest has a goal of reserving five percent of its forest as old growth.

The element that makes old growth such a unique and important wildlife feature is decay. Old growth contains an abundance of hard and soft snags, fallen logs and natural cavities in mature trees. The structure of old growth is complex and is characterized by many species that are adapted to rather specific and narrow habitat niches. Many wood warblers and several woodpeckers live in old growth and feed on forest insect pests that periodically are characterized by large outbreaks. In fact, some studies have shown that commercial forests that lack tracts of old growth are more vulnerable to insect damage because of lack of insectivorous birds that help prevent or limit such outbreaks.

Most small private woodlots will not have extensive stands of old growth. On smaller parcels, however, several types of areas should be considered for old growth designations: 1) parcels isolated by swamps or water, 2) timber of low economic value, 3) eagle and osprey nest buffer zones, 4) riparian zones, and 5) areas where esthetics are important.

Northern Hardwoods and Oak Types

Northern hardwoods are characterized by about 50 to 75 percent maple and basswood mixed with oak, yellow birch, aspen, paper birch, elm and ash. They typically have many natural cavities and a diversity of wildlife, including pileated woodpeckers, flying squirrels, white-footed mice, screech-owls, oven-birds, black and white warblers, wood frogs, red-bellied snakes, black bears, chipmunks, American redstarts, chesnut-sided warblers, rose-breasted grosbeaks, gray tree frogs, and common garter snakes. Trees known to have cavities should normally be preserved. Oak stands are also especially valuable because they are long-lived and produce acorn crops. Unfortunately, too many people value oak stands more as firewood than as food for wildlife. These forest types should not be used extensively for firewood cutting or for type conversion to conifers. These types are frequently best designated for old growth status. Whenever oaks are cut, they should be cut during dormancy and low to the ground to encourage sprouting. Grazing should be avoided. When cutting trees in a predominately oak woodlot, consider leaving some relatively uncommon tree species for the unique benefits they provide. Examples would be white pine, hickory, or black cherry. Logging slash can be used to create brush piles.

The DNR PFM Specialist should be consulted for specific management guidelines.

Aspen Forest Type

Aspen forest types are vital to the survival of ruffed grouse, woodcock, snowshoe hare, and moose. White-tailed deer, black bears, and some songbirds also use this forest type.

Aspen is primarily of interest to people who wish to manage their woodlots for grouse and woodcock. Because of the difficulties of establishing aspen where it does not exist, people hoping to manage their woods for ruffed grouse or woodcock should buy woodlots that already have a good stand of aspen. Aspen management for grouse is discussed in detail by Gullion (1984).

However, an intensive tree harvest program designed to benefit ruffed grouse will not provide for the needs of many other forest wildlife species that require older aspen stands or non-aspen habitats. While some high-quality aspen stands may lend themselves to intensive grouse management as described, most forest tracts should be managed for a diversity of wildlife and not for the maximum number of grouse that can be produced. Riparian areas, coniferous woods, old growth, oak woods, bogs, cedar swamps, and snags do not lend themselves to intensive grouse management.

Contiguous Forest Areas

Some species of wildlife require extensive forest stands that are unbroken by openings or trails. An example would be many wood warblers, tanagers, thrushes, and flycatchers. The main reason is that cowbirds are typical of forest openings and have become more abundant. They lay their eggs in the nests of forest songbirds that are in or near forest openings, and the cowbird young prevent the forest songbird young from surviving. This problem threatens some forest interior species like the ovenbird. This is not a consideration for most small woodlot owners because small woodlots are already fragmented by roads and openings. This is mainly important for large forest holdings (Robbins 1984).

Forest Openings, Gravel Pits and Trails

A forest opening is an upland area of one-half to 10 acres with few trees or brush. Gravel pits and trails are considered types of forest openings.

Forest openings are often established and maintained at log landing sites where timber has been removed. They are important because they generally contain forage grasses and legumes that are eaten by deer and other grazing animals. Small animals in openings provide prey for predatory birds and mammals. Openings are typically provided where deer management is a primary goal. There are 158 wildlife species in northern forests that use openings at some point in their lives. The Minnesota DNR has a goal that not less than five percent of the upland area of its forest management units shall be in permanent wildlife openings. These openings are often seeded with grass and legumes and are created at the site of log landings. Native species should be used when feasible. Dutch white clover is a well-used wildlife food in openings and trails but is not native.

Wildlife openings should be on south or southeast-facing slopes. They should have a 3:1 ratio of length to width. The width should be at least twice the height of the adjacent trees. Openings should be located along the edge of hardwood cut areas and be one to five acres in size. The optimum size is two to 10 acres, depending on the local situation. Seeding and maintenance of openings is essential. The area should be free of logging debris. Snake hibernating mounds or clumps of fruiting shrubs may be placed on the north edge of forest openings.

Bare ground and banks are used by 21 forest species including the belted kingfisher, snapping turtle, gray wolf, red fox, woodchuck, badger, common nighthawk, smooth green snake, killdeer, bank swallow, barn swallow, cliff swallow, and common flicker.

Cut banks at gravel pits should be preserved, and at least 50 percent of the pit floor should be bare ground. The DNR area forester or area wildlife manager should be consulted about forest opening management.

One innovative structure for use along the edge of forest openings is the "snake hibernating mound." It is essentially an underground brushpile and is designed to provide burrow sites for hibernating snakes. These mounds can be built along forest openings, road cuts, timber landings, or any land clearing which has resulted in the creation of slash and stumps. Mounds should be located on the north side of a clearing where they will receive sunlight.

Forest Edge

The edge between a cut and uncut forest or between forest and field can be good habitat for wildlife.

Forest edges should have irregular and not straight edges. This is the way natural edges occur. When cutting along edges, save special trees like den trees and tall snags. Trees, shrubs, and vines that bear nuts and fleshy fruits are valuable along woodland edges since sunlight stimulates heavy fruiting. Hickory, serviceberry, red-osier and gray dogwood, viburnum, blueberry, and grape should be preserved along forest edges.

Bird of Prey Nests and Heronries

Nesting sites of bald eagles, ospreys, hawks, and great blue heron colonies should receive special attention. These nesting sites should be reported to your local DNR area wildlife manager or regional DNR nongame specialist. They will give you advice on management of these sites.

Snags

You can allow snags to occur naturally on your woodlot or you may need to create them. Hardwood snags are preferred over conifers. However, pine and tamarack snags are long lasting and will provide good nesting and perching sites for ospreys if they are adjacent to lakes or beaver ponds.

In timber harvest areas, leave snags scattered throughout the cut area. More snags are desirable near water, oak clumps, brush piles and windrows.

In woodlots or cut areas, preserve approximately one to six hard snags per acre and as many soft snags as possible (Maser et al 1979).

In extreme circumstances where snags are lacking, you can create snags in a woodlot by girdling several diseased or deformed trees. The best trees for creation of snags are diseased or deformed oak, sugar maple, basswood, ash and elm. Aspen is also good, if mature. Select trees that are over 12 inches in diameter, when possible. Girdling involves cutting a ring around the trunk through the bark and well into the sapwood so that the cambium layer between the bark and wood is completely severed.

A good strategy for wildlife management would be to maintain a variety of snags. On a 20-acre woodlot for example, wildlife managers recommend maintaining four to five snags over 18 inches in diameter, 30 to 40 snags over 14 inches in diameter, and 50 to 60 snags over five inches in diameter (Anonymous 1981, Kitts 1981, Maser et al 1979, Thomas 1979, and Thomas et al 1979).

When snags fall down, they should be left on the ground to provide food and cover sites for birds, small mammals, reptiles, and amphibians. Logs can also provide drumming sites for ruffed grouse.

In addition to the value of fallen logs in a forest setting, logs are also important in two other circumstances. Logs can be placed on the edges of wetlands so they are partially submerged. They will be used by turtles as basking sites and by other reptiles and amphibians. Logs or platforms comprised of several logs can also be anchored in a pond to create secure sunning and resting sites for both ducks and turtles.

Lowland Conifer and Bogs

The lowland conifer forest community is unique and important. It is characterized by mineral or peat soils, acid pH, and black spruce, tamarack, and northern white cedar. Rare orchids including the stemless lady slipper, dragon's mouth orchid, and calypso orchid are found in this forest type. Deer frequently use white cedar swamps as wintering areas.

This forest type is important to the gray wolf, great gray owl, pine marten, northern bog lemming, boreal owl, least chipmunk, wood frog, Connecticut warbler, northern parula warbler, yellow rumped warbler and yellow-bellied flycatcher.

Snags and old growth are important considerations to this forest type. Great gray owl nest platforms are also a management option.

Other Vegetative and Structural Habitat Components

Planting of nut and fruit-bearing trees and shrubs can enhance the value of a woodlot. Snags, logs, rock piles, brush piles, salt licks, feeding stations, food plots, nest boxes, snake hibernating mounds, and small ponds can all be developed and maintained to enhance the value of the woodland for wildlife (Thomas 1979 and U.S.D.A. 1979).

In summary, landscaping woodlands for wildlife results in the creation or maintenance of woodlands that provide diverse habitats that benefit a broad range of wildlife while still providing opportunities for economic benefits.

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INTEGRATING HABITAT NEEDS OF MOOSE WITH TIMBER MANAGEMENT IN NORTHEASTERN MINNESOTA[1]

Peter A. Jordan,[2] Elizabeth R. Kennedy,[3] Scott D. Posner[2] and Gordon A. Weil[2]

ABSTRACT.--Where softwood production is being emphasized, plantations are established, and competing hardwoods are suppressed with herbicides. These hardwoods, however, are critical forage for moose, an important wildlife resource of northeastern Minnesota. Moose favor young plantations for the high density of forage there. It was shown that spraying 2,4-D reduces browse availability for several years by about half, and that the recently more popular chemical, glyphosate, reduces browse by some three-quarters and for a longer span. Studies of growth in white spruce relative to varying levels of surrounding shrubs suggest that current Forest Service criteria for herbicide applications are more strict than necessary. In Minnesota emphasis is now shifting from mainly softwood production to more use of aspen; its regeneration requires no plantations or herbicides. It is suggested that a timber system optimally beneficial to moose should include mixed-species interspersions. Application of new techniques such as computerized mapping coupled with modelling will be tested for achieving better integrated resource management.

INTRODUCTION

Minnesota is the only state between the Rockies and New England where moose (*Alces alces*), the largest of the deer family, are common. Granted, there is a small but growing population in eastern North Dakota, a newly introduced nucleus in upper Michigan, and the famous herd at Isle Royale National Park, Mich., an island in Lake Superior. However, Minnesota has more than a token herd, and the majority of the state's 10,000-12,000 moose are in the northeast, mainly in and around the Superior National Forest.

As a natural resource having great esthetic and economic value, moose deserve special attention from forest-land managers. For example, in the Boundary Waters Canoe Area (BWCA), one of Minnesota's most popular recreation areas, canoeists who chance to see a moose often recall this as the high-point of their wilderness trip. Presence of moose in northern Minnesota unquestionably contributes to tourism, hence to the economy. For hunters, the rare chance to take a Minnesota moose is highly prized.

Logging is common throughout the range of moose in northeastern Minnesota except in the BWCA, a designated wilderness area. Regional foresters have traditionally considered conifers, particularly red pine (*Pinus resinosa*), jack pine (*P. banksiana*), and white spruce (*Picea glauca*) to be the most valuable species, although quaking aspen (*Populus tremuloides*) and related species (*P. balsamifera* and *P. grandidentata*) are now increasingly in demand, hence gaining importance in Forest Service planning (USDA 1986).

Silvicultural practices in this region have generally centered on restocking. Typically, stands of 10-100 A are clear-cut, then prepared by rock-raking or some other technique for pulling up roots of hardwoods. Then they are planted with conifer seedlings. Even after site-preparation, subsequent control of competitors, or "release," is usually deemed necessary, and is practiced mainly with herbicides aimed at both herbaceous and deciduous-woody plants.

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[1] A paper presented at the Convention of the Society of American Foresters held in Minneapolis, MN, 18-21 October 1987 as part of Working Group C5 - Wildlife and Ecology.

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In the same areas, moose, while requiring interspersed patches of mature canopy for cover in both summer and winter, are strongly attracted to recently disturbed, upland sites such as clear-cuts. Here their preferred year-round forages-- most of the common hardwood tree and shrub species-- occur within their reach and in great abundance (Peek et al 1976, Allen et al 1988). Clear-cut patches of up to 200 A or more have great potential for supporting many moose for 10-25 yrs, after which canopy closure shades shrub-level browse production.

Site-preparation, even though severely impeding re-establishment of aspen and other fast-growing, early-successional trees, is not necessarily inimical to moose. Some suppression of vigorously sprouting species serves to keep new growth within reach (<9 ft) of moose for a longer span than otherwise. It also permits co-existence of a greater variety of deciduous species by suppressing the dominant competitors. Dietary variety is believed an important aspect of nutritional quality for moose (Miquelle and Jordan 1979). On the other hand, severe suppression of all hardwood browse in conifer plantations can greatly reduce foraging potential; and, when browse density drops below some minimum density relative to foraging efficiency, stands may become of no value at all to moose.

The purpose here is to describe our studies on how local timber practices have been affecting the quality of moose habitat. Our results can be viewed as ground work for a new synthesis of optimal coordination between producing timber and maintaining excellent habitat for wildlife such as moose, or any other species of concern. These efforts are also a direct response to the Forest Service mandate to emphasize integrated resource management.

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STUDY AREA AND ITS MOOSE

The majority of field work was done in the Tofte District of the Superior National Forest in Cook Co. of northeastern Minnesota. Soils and weather are typical of the boreal region on the Canadian Shield (Maycock and Curtis 1960, Peek et al 1976). Vegetation is mixed conifer-hardwood, with dominant trees being white spruce, balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), jack pine, paper birch (*Betula papyrifera*), quaking aspen, and, on elevated lands near Lake Superior, sugar maple (*Acer saccharum*). The most important broadleaf, shrub/tree, browse-species for moose are aspen, paper birch, willows (*Salix* spp), beaked hazel (*Corylus cornuta*), juneberry (*Amelanchier* spp), pin cherry (*Prunus pensylvanica*), choke cherry (*P. virginiana*), mountain maple (*Acer spicatum*), red maple (*A. rubrum*), mountain ash (*Sorbus americana*), bush honeysuckle (*Diervilla lonicera*), green alder (*Alnus crispa*), and red-osier dogwood (*Cornus stolinifera*). The few common hardwood shrubs not taken include speckled alder (*A. rugosa*), thimbleberry (*Rubus parviflorus*), blueberry (*Vaccinium* spp), and most species associated with lowland bogs.

Densities of moose in the study region were roughly 1-1.5/mi^2 (Minn DNR). Summer forage comprises mainly leaves of the deciduous plants listed above plus a substantial but variable amount of aquatic forage, depending on sodium needs (Jordan 1987), and some herbs taken mainly in spring and fall. In winter, current twigs of most of the same woody species used in summer are taken, along with some conifers-- balsam fir, white pine (*Pinus strobus*), and northern white cedar (*Thuja occidentalis*) (Peek et al 1976).

MOOSE-TIMBER STUDIES

We present a summary of field studies, carried out from 1983 to 1987 primarily in the Tofte District of the Superior N.F. Technical details and complete data are in theses and publication or manuscripts in preparation, while some data are not yet analyzed. We add some interpretations and recommendations, and finish with a brief description of the next steps in developing techniques for coordination of wildlife-habitat needs with timber production.

A major study objective was to estimate amounts of forage lost from plantations due to herbicide applications. Of particular interest was a comparison of effects of 2,4-D vs. glyphosate. Also we studied the suspected impacts of hardwood shrubs on young spruce in order to evaluate the criteria in use on the Forest for prescribing release treatments. And, with the recent shift to aspen management, we began evaluating browse resources in "natural-regeneration" stands.

Browse Production in Plantations and the Effects of Herbicides

Weil (1987) analyzed spruce plantations 3 to 7 years after site preparation and found that, where release treatments had not been applied, available current browse for moose averaged 89 lb/A, while sites treated with 2,4-D averaged only 56 lb/A (Table 1). Weil also found for the same plantations that estimated biomass removed by moose averaged 27 lb/A where herbicides had not been applied, compared to 18 lb/A in the treated sites.

Table 1.--Biomass and consumption by moose of current-year twigs and leaves of deciduous, moose-browse species in 3-7 year-old spruce plantations, comparing stands sprayed with 2,4-D vs. those not sprayed.

	lb(dry)/A	
Treatment	No Herbicide	Herbicide
No. of stands	10	11
Biomass	88 (±7.1)[a]	56 (±8.0)[b]
Removed by moose[1]	27 (±3.3)	18 (±2.7)[b]

[1] Reconstructed by difference.

[a] Standard error

[b] $p < 0.05$

Kennedy (1986) and Kennedy and Jordan (1985) compared the impact of two herbicides, 2,4-D-- used commonly in the 1970s, and glyphosate ("Round-up")--the more preferred chemical of the early 1980s, on hardwood browse in plantations. They found that available browse in stands treated with glyphosate was roughly one-half that in 2,4-D treatments, and the latter was roughly one-half that in untreated stands (Table 2). Weather during treatment can strongly influence the effectiveness of herbicides. Note that differences among 1982-treated stands suggest there were no impacts; because summer 1982 was dry, target species were already dormant hence, not very vulnerable when sprayed.

Table 2.--Biomass of current-growth, deciduous, available moose-browse (leaves and twigs), comparing among two herbicides and a control on plantations treated in three different years. Each entry represents an average of biomass from plots within 3-5 stands, all measured in late-summer 1985 (Kennedy 1986).

	lb(dry)/A		
Treatment	Glyphosate	2,4-D	Untreated
Year Sprayed			
1981	52 (39)[a]	97 (36)	-
1982	96 (81)	81 (30)	-
1983	21 (28)	101 (9)	201 (72)

[a] Standard deviation

At the time of this study there were no examples in our area of glyphosate treatments that were more than 5 yrs old; hence we were unable to evaluate its longer-term effects. However, it appears that this herbicide, when applied as intended, kills entire root systems. In contrast, 2,4-D kills back only the tops in most browse species, allowing for reasonable regrowth within 3-5 yrs. In the latter case, spruce should grow above the slowly recovering deciduous plants, so that the needs of both moose and timber are met. Glyphosate, in contrast, may eliminate abundant browse for the remaining years over which the plantation would provide space and light for shrub growth. On the other hand, because glyphosate is probably the least health-threatening of herbicides to humans and other vertebrates, its use is recommended for hand application around individual conifer saplings where specific need is indicated.

Effects of Hardwood Browse on Young White Spruce

The issue of when to release plantations for preventing suppression of young white spruce, the most commonly planted species in our study area, was analyzed. From the standpoint of moose habitat, the question is rephrased: how long can hardwoods be left unsprayed before spruce growth is measurably suppressed? Posner (1984) and Posner et al (ms) sampled growth performance in 5-16 year-old spruce, using extent of shrubs surrounding individual saplings as the independent variable. It was found that, for all sapling ages examined, better growth was associated with some surrounding shrubs than with none. In the younger saplings, growth suppression was not positively correlated with increasingly heavy shrub densities, but it was related negatively as shrub density approached none (Table 3). Saplings over 9 yrs appeared more sensitive to heavy-shrub presence.

The overall conclusion was that Forest Service guidelines on timing of release were more cautious than needed. Were guidelines relaxed to better reflect the observed interaction between spruce and surrounding shrubs, chemical treatments could be delayed longer or omitted. This would save browse for moose and other wildlife, and it would save costs in softwood regeneration.

It should be noted that, where production of spruce is the objective, moose themselves can aid silviculture. Moose do not touch spruce, but they readily take most of its broadleaf competitors and even some coniferous ones, e.g. balsam fir. The greater the moose density, the more they will suppress broad-leaved perennials. At Isle Royale, where moose densities are as high as reported from anywhere, there are extensive areas in which all upland hardwoods are so suppressed by moose that they seldom exceed 6 ft (Krefting 1974, P. Jordan unpubl). Such extreme pressure is excellent if spruce or other nonpalatable species, e.g. jack

Table 3.--Current annual height increment and total height in 7-9-yr-old white spruce according to levels of surrounding shrubs (Posner 1984).

Shrub[1] Level	Current-Yr Height Increment (in)	Total Height (in)
None	11 b	61 b
Low	12	75 a
Medium	14 a	83 c
Heavy	14	79 c

[1] Shrubs included all hardwood bush and tree species. "Level" was a combined measure of densities, heights, and over-topping positions of stems within a circle around the sapling.

a, b, c: entries in the same column with different letters are significantly different, $p < 0.05$.

pine, are the only trees of commercial interest. It would not work, however, where balsam fir, white pine, birch or aspen is the expected timber crop. In any event, for moose to increase to high densities, quality and quantity of available browse must be abundant.

Browse Production and Natural Regeneration

The recent forest-industry shift to extensive use of aspen is leading to more stands in the Superior N.F. being managed for natural regeneration. Our studies were correspondingly shifted to measure browse characteristics under natural-regeneration management. Although these data have not yet been analyzed, some general observations can be offered. While great losses of forage from effective herbicide applications are totally contrary to moose management, too much browse production is not necessarily ideal either. Where aspen is resprouting vigorously and the stand is very large or local moose density is low, the sprouts tend to out-reach moose in 10 yrs or less. Then the site's value to moose rapidly declines, because much of the annual growth is unavailable, and the aspen is crowding out other favored species which moose seek to diversify their diets.

DISCUSSION AND CONCLUSIONS

For public forest lands in northeastern Minnesota, interactions between timber economics and recreational expectations create a demand for an integrated, multiple-use approach to management over the landscape. Commercial potential from forest products here is modest compared to the intensive timbering regions of the U. S. At the same time, the Superior National Forest and adjacent public lands offer an immense recreational potential for vacationers from throughout the upper Midwest. Therefore, realistic integrated resource management must reflect the fact that wildlife and scenic considerations rate comparably with, if not higher than, forest products. Such recognition is indeed reflected in the recent 10-year plan of the Superior National Forest (USDA 1986).

Interpretations and Recommendations

Timber extraction and intensive silviculture need not conflict with maintaining good habitat for moose. This applies to many other important types of wildlife as well: bears and ruffed grouse, as pointed out by Rogers and Gullion respectively in these proceedings; plus deer, hares, and beaver. Important predators, such as the federally listed timber wolf in Minnesota, are in turn favored by high densities of forest herbivores associated with early succession vegetation. The question then is how does management optimize for all these public and commercial concerns on the same land at the same time.

Our studies suggest there are positive and negative aspects for moose in each timber-regeneration practice in use today. Clear-cutting in this region is widely viewed as favorable to wildlife, since it mimics fire and windthrow to which many common species are well adapted. Current Forest Service guidelines for clear-cutting provide for an ample interspersion of cover patches and snags to serve a wide variety of wildlife. Site preparation prior to planting, because it reduces vigorous sprouting by a single species, can favor moose by keeping browse available longer and in greater diversity. However, sometimes site-preparation leads to scraping off patches of shallow top soil; this reduction of basic productivity is deleterious to all interests.

Heavy use of herbicides to control competition, particularly chemicals that kill entire root systems, causes major loss of browse potential associated with clear-cutting. On the other hand, natural-regeneration management can lead to rapid escape of post-disturbance emergents, leaving moose too few years to benefit from the forage. Obviously, optimization of moose and timber calls for some intermediate strategy, such as a mixing of commercial-tree species within stands.

Northeastern Minnesota can expect the demand for both softwoods and hardwoods to continue indefinitely; thus timber planning must provide for future supplies of both. Traditionally, managers and forest operators prefer uniform stands with one species per stand. However, if some stands were comprised of intermixed patches of conifers and emerging hardwoods, better habitat would be provided for moose in terms of cover and forage over a longer span of years. Herein lies a major challenge-- to design a mixed-species silviculture that is economically reasonable, from regeneration to harvest, and is a better solution to moose needs than possible with any combination of monocultur stands. We believe this is a reasonable goal

Management Tools of the Future

There is a strong need to bring recent computer-based technologies within reach of forest-land managers. These include techniques for evaluating condition and future potential of wildlife habitats, for inventorying timber resources, for projecting vegetative growth over many decades, and for reaching management decisions from inputs of economic, ecological, environmental, and recreational constraints. All such activities, furthermore, must be designed in parallel with wholly compatible information bases, so that criteria for one resource, e.g., wildlife, can be directly translated into realistic prescriptions for another resource, e.g., timber. Good progress has already been made within the Forest Service, but greatly expanding opportunities for computer applications lie ahead.

Technological applications can be developed today with an efficiency not possible just a few years ago. New methods include coupling computerized mapping (geographic information systems = GIS) with computer models of forest succession or of responses by wildlife populations to environmental events. For example, a habitat-suitability index model for moose of the Lake Superior region has just been completed (Allen et al 1988) and will soon be tested on the Superior N. F. Land-based, resource data-bases in turn can be coupled with decision-making models that incorporate all economic and environmental constraints for the purpose of examining various management options. It is along these lines that our research and development efforts with the U. S. Forest Service will next be directed.

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INTEGRATING WILDLIFE HABITAT OBJECTIVES WITH SILVICULTURAL PRESCRIPTIONS[1]

John E. Mathisen[2]

ABSTRACT.--Land managers need methods to assess, measure and predict the affects on wildlife of vegetation change resulting from silvicultural prescriptions. A data base was developed to relate vertebrates on the Chippewa National Forest to their habitats and special requirements, providing a simple method of comparing alternative land use proposals in terms of species richness and selected groups of species.

INTRODUCTION AND OBJECTIVES

Seldom do forest managers apply pure silvicultural prescriptions to land managed for a variety of uses. More often than not, the best and most appropriate silvicultural practice is modified to accommodate resources other than timber. This modification, often for a wildlife habitat need, may diminish the production of timber or increase management costs. The National Forest Management Act and other laws and regulations clearly mandate the USDA Forest Service to integrate wildlife habitat needs into the planning process, and further directs managers and planners to assess the affects of land management proposals on plant and animal diversity. Therefore, it becomes imperative that effects and trade-offs are understood and measurable, so that rational and informed interdisciplinary decisions can be made.

This paper has two objectives:

1. To display the relative value of forested communities in northcentral Minnesota in terms of vertebrate species richness, and for species having special status, and

2. To describe, in terms of animals and their habitat relationships, an analytical technique to display the effects of modifying silvicultural prescriptions to meet wildlife habitat objectives.

SILVICULTURAL VS INTERDISCIPLINARY PRESCRIPTIONS

Silvicultural practices are designed to grow trees as quickly and efficiently as possible, with the ultimate objective of producing a high quality forest product. A wildlife habitat objective for the same land unit may require somewhat different type composition, age class distribution or stand features and may conflict with the best silviculture. While this wildlife objective may relate to a single species or group of species, ecologically-based management requires objectives and associated analytical methods related to communities and the elusive objective of "diversity" (Siderits 1975).

Composition objectives are guides designed to integrate forest type composition and age class distribution among resources over large landscapes. In the parlance of National Forest planning in the Eastern Region, this is part of the Desired Future Condition (DFC), setting the stage for "proactive" decision-making as opposed to the traditional and less desireable "reactive" mode. Composition objectives provide the framework on which to hang all other decisions relating to vegetation management over long time periods. It is an essential element in the conceptual framework of Integrated Resource Management (IRM) (USDA Forest Service, 1985).

The DFC concept is refined further by incorporating the preservation, enhancement or creation of specific stand features to integrate wildlife habitat objectives with silvicultural objectives. Some examples are:

- Deferral of harvest for old growth
- Retention of snags
- Retention of mast trees
- Retention of selected trees or tree groups for diversity
- Modification of stand size or configuration

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[1] A paper presented at the Society of American Foresters Annual Convention held at Minneapolis, MN, October 18-21, 1987.

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How, then, can we rationalize and estimate the effects of altering silvicultural prescriptions for wildlife benefits? This has always presented a problem for land managers due to a lack of organized empirical information on habitat needs for all but a few game species. With the NFMA as a catalyst, the concept of Wildlife Habitat Relationships (WHR) evolved within the Forest Service in recent years to provide the tools and information needed to deal with the problem (Nelson and Salwasser 1982). We developed a system on the Chippewa National Forest called "Wildlife Habitat Associations" (WHA), which is a computerized data base designed specifically for the wildlife species and community types on the Forest, although it has been adopted and utilized throughout the Lake States and beyond. Land use proposals are weighed and alternatives compared in terms of entire wildlife communities (species richness), or for selected species or groups of species (such as threatened, endangered, sensitive, or game/fur). It is very user-friendly, and has proven to be a powerful tool (Mathisen 1982, 1983, 1985).

THE DATA BASE

In 1981, we assembled a group of 11 biologists and naturalists with local knowledge of wildlife and their habitat associations on the Chippewa. This group gathered a library of reference material and, together with their combined experience and knowledge, compiled information on the vertebrate species occurring on the Forest.

We used 8 interrelated components correlating 311 vertebrate species with habitat, season of use and status. Using the classification of Niemi and Pfannmmuler (1979), 24 communities or animal habitats were used to accommodate the vertebrates on the Chippewa, reflecting vegetation, successional stage (age) and structure. Fourteen of these were forested communities.

Using the method of Thomas (1979), each species was categorized according to the communities commonly utilized for feeding and/or breeding. Because most species were oriented to more than one community, an attempt was made to assign one of them as the "critical community." It was impossible to assign a critical community to the more ubiquitous species.

Eight categories were used to relate special habitat requirements to each species: man-made structures, edge, decaying log, snags, riparian areas, mast and banks or bare ground.

Special status was based on four categories: game/fur, threatened/endangered, sensitive and management indicator species.

For this paper, I have compiled data base elements for the forested communities only; aquatic, wetland and other non-forested habitats are rarely altered with silvicultural decisions. Presentation further simplified by combining breeding and non-breeding use of the habitats.

The forested communities in the data base represent an assemblage of forest types with similar wildlife associations. They are:

Deciduous upland	Oaks, aspen, birch, northern hardwoods
Coniferous upland	Red, white and jack pine, spruce-fir
Coniferous lowland	Cedar, black spruce, tamarack
Deciduous lowland	Ash, elm

Each species was also classified according to their association with four age groups within each community:

Shrub/Sapling	Regenerating stands <10 years old
Young	>10 and <70 years old, depending on forest type
Mature	>70 and <120 years old, depending on forest type
Old growth	Beyond normal rotation age

Both type and age must be considered to assess importance and to evaluate alternatives, as demonstrated by DeGraff and Chadwick (1987).

Recently, a direct linkage was made between the WHA data base and the Eastern Region's Vegetation Management Information System (VMIS), expanding the analytical potential and usefuleness of both data base systems.

IMPORTANCE VALUATIONS OF COMMUNITIES

What are the relative values of the four communities in terms of vertebrate species richness and in terms of species having special status? Species richness is a simple, although incomplete, measure of diversity, further defined in this context as "alpha" or within-stand diversity (Whittaker 1972). Table 1 shows the orientation of all the vertebrates on the Forest to the four communities, without consideration of community age or size. This is an expression of species richness.

TABLE 1.--Orientation of Wildlife to Generalized Communities in Terms of Species Richness.

Forest	Deciduous Upland		Coniferous Upland		Coniferous Lowland		Deciduous Lowland	
Total	No.	%	No.	%	No.	%	No.	%
Birds								
233	86	36.6	66	28.3	52	22.3	51	21.9
Mammals								
57	41	71.9	36	63.1	28	49.1	25	43.8
Herps								
21	12	57.1	9	42.8	2	9.5	8	38.1
311	139	44.7	111	35.7	82	26.4	84	27.0

Clearly, species richness is highest in the deciduous upland types, with 139 species having this orientation (44.7 percent of all the species on the Forest). The coniferous uplands rank second in species richness, and the lowland types are at the low end of the diversity scale.

To the forest manager making a decision on what forest type to emphasize, this indicates that, in terms of within-stand diversity, the deciduous types are preferred. If the best silvicultural decision for a particular stand was to convert it from deciduous to conifer, the potential affect would be a 20 percent decrease in species diversity (20 birds, 6 mammals, and 3 reptiles and/or amphibians). This would be taken into consideration at the interdisciplinary level of decision-making.

This affect can be further supported by summarizing, in Table 2, the critical community element in the data base.

TABLE 2.--Critical Community Associations of Wildlife (number of species).

	Deciduous Upland	Coniferous Upland	Coniferous Lowland	Deciduous Lowland
Birds	34	23	5	2
Mammals	7	3	2	1
Herps	0	0	0	0
	--	--	--	--
Total	41	26	7	3

The deciduous uplands are critical habitats for 41 species, compared to 26 in the conifer types, and very few in lowland forested types. Relative to other forested communities on the Chippewa, this further supports the value of deciduous uplands.

The relationship of special status species to the four communities is shown in Table 3. In this table the threatened, endangered, and sensitive (T/E/S) species are combined, and game and fur (G/F) species are combined.

TABLE 3.--Relation of Special Status Species to Communities (number of species).

Forest Total	Deciduous Upland No.	Deciduous Upland %	Coniferous Upland No.	Coniferous Upland %	Coniferous Lowland No.	Coniferous Lowland %	Deciduous Lowland No.	Deciduous Lowland %
T/E/S 20	6	30.0	10	50.0	10	50.0	4	20.0
G/F 53	24	45.3	13	24.5	9	17.0	14	26.4
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73	30	41.1	23	31.5	19	26.0	18	24.6

Table 3 shows the relative value of the four communities when the management objective is to favor either or both of the T/E/S and G/F species. G/F species clearly favor deciduous uplands, where 24 of 53 species occur. T/E/S species are associated more with coniferous upland and lowland communities. Considering the special status species as a group, the deciduous uplands support more species than any other.

The forest manager, therefore, can objectively evaluate the effects of silvicultural alternatives concerning forest type emphasis in terms of wildlife species that, because of their status, merit special management considerations.

By computing a "wildlife habitat capability" score for each community considered, and totaling the four evaluation criteria (Table 4), this analysis can be carried one step further, providing the manager with data on the relative value or ranking of all four communities based on the sum of species richness value, values for critical community and special status species.

TABLE 4.--Wildlife Habitat Capability (WHC) of Four Communities.

Community	Species Richness	Critical Community	T/E/S	G/F	Total WHC
Deciduous Upland	139	41	6	24	210
Coniferous Upland	111	26	10	13	160
Coniferous Lowland	82	7	10	9	108
Deciduous Lowland	84	3	4	14	105

The fact that the deciduous upland community has the greatest capability does not mean that wildlife is best served by having only this community available. Each supports a unique assemblage of animals and, without the presence of conifer components, some species would be at very low population levels or non-existent. This leads to another level of analytical procedure.

An aggregation of communities is an expression of another aspect of diversity, called beta diversity or between-stand diversity, and considers species distribution in a wider context. This analysis is done at the interdisciplinary level for application to large landscapes such as compartments, opportunity areas or management areas. It becomes more complex, but the data base and the concept of WHC is utilized to assess land areas by relating WHC to the amounts of each community present. The end result here is an index value called the Habitat Capability Index (HCI). This value can be used to assess wildlife implications among alternative strategies for the DFC during the initial stages of planning.

Age, or successional stage, is another aspect of habitat valuation reflecting the structural characteristics of a community. The age relationship is much more dynamic than community type. A regenerating stand today may be a young stand within 10 years, and may have old growth features within 80 years. As age progresses, associated wildlife changes dramatically. Site index and rotation age, therefore, become important considerations for assessing value and predicting the future. The data base contains information on the orientation of wildlife to four age classes (Table 5).

TABLE 5.--Average Number of Species in Each of Four Age Classes.

Age Class	Species All	 G/F	 T/E/S
Shrub/Sapling	130	20	6
Young	65	10	3
Mature	84	13	6
Old Growth	80	11	6

The relative value of community age in terms of species richness is highest in regenerating stands, and lowest in young stands. As the stand matures and becomes more vegetatively complex, species richness increases, falling off slightly when the old growth condition is reached. Game/fur species have a particularly strong orientation to the shrub/sapling stage, with about equal representation among the other three. Threatened, endangered and sensitive species show no particular affinity to age class.

To the land manager concerned with diversity as a management goal, this means that cutting is good, and reducing rotation age will generally be favorable. A timber sale in a mature stand will have the immediate effect of increasing within-stand diversity from an average of 84 to 130 potential species; about a 54 percent increase. As with forest type distribution, a patch-work of age classes contributes to between-stand diversity and becomes an important element in describing the DFC. In practice, both community type and age are considered simultaneously, and the HCI is computed on this basis.

The data base can thus be used as a simple model to predict effects of alternative prescriptions over time in terms of the HCI.

SPECIAL HABITAT REQUIREMENTS

In addition to communities and age classes, there are special requirements that must exist before habitat is suitable for some species. Snags for pileated woodpeckers are mandatory, while riparian habitat for raccoons is important, but notessential. We considered seven special requirements for the data base. Five of these are important when making silvicultural prescriptions: snags, edges, downed logs, mast, and riparian areas

We are in the process of adding new information to the data base reflecting minimum habitat size for birds to evaluate the effect of forest fragmentation on avian species (Robbins 1979, Anderson and Robbins 1981). When this is done, we will be able to quantify and compare management schemes favoring edge-associated species with those favoring large, contiguous areas of forest cover.

These elements provide another level of detail to evaluate in relation to the species in the four communities. Table 6 shows the number of species in each community having one or more of these special requirements.

TABLE 6.--Special Requirements of Vertebrates Associated With Forested Communities (number of species).

	Total Species	Snags No.	%	Edge No.	%	Logs No.	%	Riparian No.	%	Mast No.	%
Deciduous Upland	139	49	35	73	53	51	37	51	38	15	11
Coniferous Upland	111	36	32	53	48	45	41	38	34	17	15
Coniferous Lowland	82	23	28	37	45	27	33	31	38	11	13
Deciduous Lowland	84	27	32	38	45	30	36	40	48	7	8

Snags

Wildlife species requiring dead or dying trees are present in all communities, ranging from 49 species in deciduous uplands to 23 in lowland conifers. Therefore, it becomes imperative, from the species diversity standpoint, to ensure that this stand feature is present in all communities and reflected in prescriptions. Silvicultural practices that discriminate against dead or dying trees, such as salvage cuts and fuelwood removal, must be carefully considered. The number of snags required to accommodate snag dependent wildlife were computed for each community (Thomas 1979) and incorporated as a standard in the Forest Plan.

Edge

Species having an orientation to edges or ecotones range from 73 in deciduous uplands to 37 in the lowland conifer types. Although some ecotones are natural due to soil or moisture gradients, others can be induced through management. Edge habitats can be enhanced by prescribing relatively small, well-dispersed stands. High levels of between-stand (beta) diversity will generally produce high levels of edge habitat. Preserving within-stand features, such as conifer inclusions in deciduous stands and vice versa, will enhance edge habitats as well as within-stand diversity. Configuration of cutting unit boundaries is also related to edge. The more complex configurations will produce the greatest amount of edge. Conversely, some species (primarily birds) associated with the forest interior may be negatively effected as edge increases and stands become smaller.

Downed Logs

Most mature and old growth stands contain an abundance of stumps and downed logs from natural mortality and storm damage, unless silvicultural practices such as salvage cuts and slash removal have removed them.

While all communities support a substantial number of species requiring downed logs, species associated with coniferous uplands are particularly dependent on downed logs, with over 40 percent of all the species in this community having this requirement. Silvicultural prescriptions involving salvage operations, fuelwood gathering, prescribed burning and slash removal should be carefully considered to ensure this element of habitat is not depleted.

Riparian Associations

Where water and upland come together, a riparian habitat is featured. This is an important wildlife association, ranging from 51 species in deciduous uplands to 31 in lowland conifers. Many of the species associated with the old growth condition are also associated with riparian areas (40 in deciduous upland, 31 in coniferous upland, 30 in deciduous lowland, and 21 in coniferous lowland). High priority is given to extending rotation ages for old growth management in stands classified as riparian. Snag-users and downed-log users are disproportionately associated with riparian areas, and these stand features should be emphasized in these areas.

Mast

Mast produced by trees and shrubs is utilized as a food source by wildlife in all communities, ranging from 17 species associated with upland conifers to 7 in lowland deciduous types. While mast is provided by a number of trees and shrubs (e.g., oak, pine, and hazel), acorns are essential to important game species such as deer, black bear, and waterfowl. Silvicultural decisions should provide for retaining oak components as within-stand features in all communities, but especially in coniferous upland and deciduous upland types.

CONCLUSION

While the Wildlife Habitat Association data base does not answer all the questions on timber/wildlife relationships, it does provide an objective and organized way of dealing with wildlife habitat values and the consequences of silvicultural and other land use proposals. The WHA data base is directly linked to our Vegetation Management Inventory System (VMIS) through the animal habitat component where WHC values are automatically generated and displayed on a stand-specific basis. Foresters and wildlife managers can now discuss, with less ambiguity than ever before, the relative merits of alternative management strategies. The final decision, as always, rests with the overall goals and objectives by which the land management system is driven.

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KIRTLAND'S WARBLER BREEDING BIOLOGY AND HABITAT MANAGEMENT[1]

John R. Probst[2]

ABSTRACT.--The Kirtland's warbler (Dendroica kirtlandii) is an early succession, area-sensitive species seldom found in stands smaller than 30 to 40 ha. This warbler occupies dense jack pine (Pinus banksiana) stands where trees are from 6 to 23 years old and from 1.7 to 5.0 m high growing on poor, sandy soils. Typically, it has been found in areas regenerated naturally by serotinous cones resulting from wildfires. In the past 2 decades, however, Kirtland's warblers have been found in naturally regenerated, unburned jack pine and in densely stocked pine plantations. Stands are managed on a 50-year rotation and clustered into discrete management areas. Extensive dispersal to find suitable habitat reduces breeding opportunities. Currently, about 15 percent of the males abandon territories, and about 15 percent of the resident males do not find mates. Clustering stands into management units and staggering the schedule of stand regeneration should minimize biogeographic dispersal problems. Because Kirtland's warblers colonize patches of taller, dense jack pine before they occupy habitat with shorter or less dense trees, the period of Kirtland's warbler occupancy in a management area can be extended by several methods such as varying tree spacing in a plantation. Researchers and managers have developed a variety of harvest options, site preparation methods, and pine regeneration alternatives for providing suitable Kirtland's warbler habitat. Several options do not require the use of prescribed fire. These management alternatives must not only provide suitable tree stocking and spacing for the Kirtland's warbler but also accommodate their spatial and temporal needs such as the size, chronology, and age diversity of stands.

The Kirtland's warbler (Dendroica kirtlandii) is an Endangered Species that is only known to breed in young, jack pine (Pinus banksiana) habitat in northern Lower Michigan. This warbler migrates to the Bahamas where it winters in low, broadleaf scrub habitat. The known breeding population is censused annually and has averaged 205 males from 1971 through 1987. The breeding population has been remarkably stable, ranging between 200 and 216 males for 12 of the past 17 years. The Kirtland's warbler occupies dense, jack pine stands where trees are from 5 to 23 years old and from 1.7 to 5.0 m tall. Typically, this habitat has been regenerated naturally by serotinous seeding resulting from wildfires in jack pine on sandy, porous soil. In the past 2 decades, however, Kirtland's warblers have been found in naturally regenerated unburned jack pine and in densely stocked pine plantations.

I will review and describe four general areas of Kirtland's warbler biology and management: (1) the habitat requirements of the Kirtland's warbler, (2) the demography of the Kirtland's warbler and the evidence for population regulation by habitat limitation, (3) a hypothesis of how geography of suitable habitat affects stand colonization success and duration of habitat occupancy, and (4) the management strategies and recommendations needed to meet Kirtland's warbler requirements for optimal spatial and temporal distribution of high quality habitat.

KIRTLAND'S WARBLER HABITAT REQUIREMENTS

The most obvious difference between occupied and unoccupied suitably aged jack pine habitat is the dense tree stocking of the stands used by Kirtland's warblers. Areas with less than 20 percent canopy cover rarely are used for breeding. Optimal habitat typically has more than 7,500 stems per hectare and between 35 and 65 percent canopy cover. Tree canopy cover is more useful for evaluating habitat quality than stocking frequency or stem density because it combines tree stocking, spacing, and height factors. In any stand, the stocking should have from 20 to 25 percent tree cover to have a good chance of occupancy. Plantations can be adequately stocked for Kirtland's warbler breeding with only a minimum of 2,800 stems per hectare because planted trees are less clumped than those in naturally regenerated areas. Red pine (Pinus resinosa) plantations have had breeding Kirtland's warbler in places where they are planted closely enough to satisfy Kirtland's warbler stocking requirements. Unburned jack pine clearcuts that are stocked from nonserotinous natural seeding have less than 20 percent of the tree density of areas regenerated by wildfire and are almost never stocked enough to be suitable breeding habitat. However, if unburned stands have more than about 2,000 stems per hectare, Kirtland's warbler may breed there at low densities and for a short duration. Jack pine habitat that has low productivity for Kirtland's warbler is characterized by tree foliage volume that is less than that found in areas considered to be suitable habitat. Suitable or optimal habitat is also marginal when it passes through the young stage where trees are short and foliage volume is low. The two classes of marginal habitat have low Kirtland's warbler productivity because of low male density, low pairing success, low site tenacity, and late breeding initiation.

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Tree Foliage Volume

At least six trends identify tree foliage volume as the major factor of Kirtland's warbler habitat suitability. (1) Areas with dense regeneration are occupied first and those lacking minimal tree stocking are never used. (2) Stands of intermediate tree density are older than dense stands when first used (Buech 1980) and usually support fewer birds. (3) Territory sizes tend to be larger in the more open areas of a stand (Mayfield 1960, Smith 1979). (4) The average density of male Kirtland's warblers is higher in well-stocked plantations or wildfire areas (Probst MS). (5) Kirtland's warblers arrive later in the season in breeding areas with minimal foliage volume (marginal habitat) than in more suitable habitat, and abandon marginal habitat with greater frequency. (6) Pairing success of males in young or poorly stocked habitat is from one-half to two-thirds that in more suitable habitat (Probst and Hayes 1987). Because tree foliage volume is so important to Kirtland's warbler habitat suitability, the occupied habitat can be described by a range of tree heights and tree covers. The composition and height of ground cover become limiting outside the bounds of poor sites selected for Kirtland's warbler management.

I have hypothesized that the well-defined habitat requirements of this species can be explained by its foraging ecology. The upper and lower limits of stand age (tree height), tree density, and ground covers can be related to their foraging heights, sites, and modes. The canopy cover threshold for initial occupancy may be related to minimal foliage volume necessary for Kirtland's warbler foraging requirements. The decline of habitat could be related to a lack of live, lower branches (Probst MS) for fledgling cover and for foraging space for the female (unpublished data).

Stand-Age Population Trends

Populations in burns generally build for 3 to 5 years after first occupancy, level off for 5 to 7 years, and decline rapidly within 3 to 5 years (fig. 1). In general, stands are not colonized by Kirtland's warblers until the average tree height reaches from 1.4 to 2.3 m (Probst MS). Breeding areas support highest male densities during the middle period of Kirtland's warbler occupancy (Probst 1986), at which time stands range from 2.4 to 3.9 m tall. Populations begin to decrease when tree heights reach 3.5 m or more and no live foliage is present below about 1.0 m. During the middle period of occupancy when Kirtland's warbler densities are highest, tree cover is between 27 and 60 percent, a condition found in fire-regenerated stands that typically have stem densities in excess of 5,000 per ha (Probst MS). Because trees are evenly distributed in plantations, optimal tree canopy cover can be produced with a tree density as low as 3,000 stems per ha.

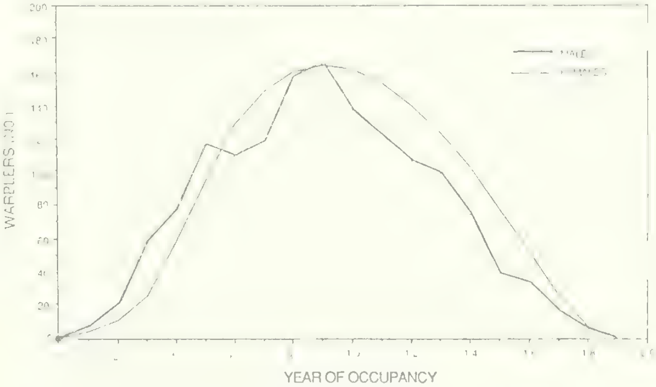

Figure 1.--Stand age population trends of male and female Kirtland's warblers. The male data were averaged from four wildfire areas in Michigan centered about the median year of occupancy. The female curve was inferred from data on pairing success in young versus older habitat (see text).

Ground Cover

Previous explanations of Kirtland's warbler habitat suitability have centered about the bird's nesting biology (Mayfield 1960, Walkinshaw 1983). The Kirtland's Warbler Recovery Team (appointed under authority of the Endangered Species Act of 1973) has emphasized the importance of fire to provide appropriate ground cover for nests, which are always on the ground. However, recent data show that on the very poor quality sites that characterize Kirtland's warbler habitat, ground cover does not appear to be limiting to Kirtland's warblers habitat selection. Both occupied and unoccupied stands almost always have a low, light cover of shrubs and grass-sedge interspersed with moss, lichen, and bare ground. Although initial post-fire ground cover species composition differs between burned and unburned stands, these differences decrease as stands mature (Abrams and Dickman 1982). This trend toward convergent succession of ground cover vegetation when the stand is from 3 to 5 years of age has been confirmed in longer-term comparisons within sites that have varied fire and shade histories (unpublished data). Thus, I propose that ground cover vegetation on these poor-quality jack pine sites is not significantly altered by fire because most plant species present are fire adapted and regenerate quickly from underground roots or runners. The primary factors that influence ground cover species composition, instead of fire history, are site quality and recent shade history.

Broadleaf Coppice

Because the Kirtland's warbler has been found frequently in nearly pure jack pine stands, it has been thought that sprout growth from Northern pin oak (Quercus ellipsoidalis), big tooth aspen (Populus grandidentata), black cherry (Prunus serotina), and choke cherry (P. virginiana) would make the habitat unsuitable. However, it is likely that Kirtland's warblers are adapted to moderate amounts of oak, and they have been found at maximum densities in breeding areas with as much as 20 percent oak (Smith 1979). Broadleaf coppice is actively used for foraging, so it should not be detrimental if jack pine stocking is adequate. Broadleaf sprout-growth is beneficial in marginally stocked jack pine stands because it provides supplemental foliage volume for Kirtland's warbler foraging.

POPULATION REGULATION

Cowbirds

It is possible to conduct a comprehensive census of singing male Kirtland's warblers during the breeding season because of their distinct habitat requirements and restricted breeding range. Such censuses were done in 1951, 1961, 1971, and every year thereafter.

The population of singing males decreased from 502 to 201 between 1961 (Mayfield 1962) and 1971 (Mayfield 1972). The major reason for this population decrease appeared to have been nest parasitism by the brown-headed cowbird (Molothrus ater) (Ryel 1981). However, the population has stabilized since cowbird control beginning in 1971 cut parasitism rates from more than 66 percent of the nests (Walkinshaw and Faust 1974) to less than 3 percent (Kelly and DeCapita 1982). Productivity increased from less than 1 to 3.1 fledglings per pair (Walkinshaw 1983).

Fledgling survival rate may be as high as 75 percent per year (Probst 1986), so high winter mortality (Ryel 1981) is an unlikely explanation for the failure of the population to increase since 1971. The factors that may now be limiting population growth are habitat maturation and fragmentation, incomplete pairing success, fledgling mortality, and yearling dispersal to less suitable habitat or places outside the known breeding range.

Habitat

Strong evidence exists that the availability of suitable breeding habitat has been the principal factor limiting Kirtland's warbler population since cowbird control was begun. Because habitat is only suitable for a 10- to 16-year period, habitat maturation forces young birds to find new breeding areas. Thus, populations can be maintained or increased only if new breeding colonies are established to replace existing areas. Suitable breeding habitat available to the Kirtland's warbler has decreased since 1961 (Ryel 1981, Probst 1986). The amount of jack pine habitat in the 8 to 20 year stand-age range has not decreased much since 1951, but indirect evidence exists that the amount of suitable habitat (adequately stocked with jack pine) has declined significantly during the past 35 years. The density of male Kirtland's warblers in all suitably aged habitat fell from 3.0 males per 40 ha in 1961 to 1.0 males per 40 ha in 1984 (Probst MS). However, warbler densities in occupied habitat were similar in 1951 and the period from 1981 to 1985, even though the entire population has declined about 40 percent since 1951. This implies that the Kirtland's warbler population might have been filling most of the suitable habitat in recent years, with some overflow into less suitable or marginal habitat.

The population stability since 1971 could be related to population regulation by a fairly constant area of habitat. The minor population fluctuations that have been observed during the past 17 years have been related to a synchronous increase or decrease at maturing colonies (Probst 1986) and higher or lower proportions of Kirtland's warblers in suitable versus marginal habitat (Probst and Hayes 1987). The recent concentration of Kirtland's warblers into a small portion of the available suitably aged habitat is further evidence of population affected by the amount of suitable habitat. In the period from 1977 to 1983, three-fourths of the male population (between 155 and 180 males) was located in five or six major breeding areas (Ryel 1981, Probst 1986) whose combined total area represented only about one-third of the entire occupied habitat. This population concentration suggests that highly suitable habitat was limited to five large burns and one management area. Finally, the within-season movement pattern of Kirtland's warblers suggests that many birds are not breeding but are searching for better quality habitat (see below).

BIOGEOGRAPHY AND HABITAT UTILIZATION

Habitat area may affect colonization success, arrival dates, territorial establishment, and fledging dates. A scarcity of quality habitat may result in more territory being abandoned because birds may have to search for better nesting territories in order to secure a permanent pairing. In 1982 and 1983 about 15 percent of the resident males did not find mates (Probst and Hayes 1987). Any dispersal to find more suitable habitat may reduce breeding opportunities. Delays in the initiation of breeding may cause birds to miss food resource peaks or sacrifice opportunities for renesting or second nesting. In 1987, about 22 percent of the male Kirtland's warblers abandoned territories established before 21 June. They could not have raised broods by that date. However, the colonization and dispersal patterns differ between marginal and suitable habitat. A higher proportion of males abandon territories in marginal habitat than in suitable habitat (1987 data in Fig. 2). In 1986, 93 percent of the territories in suitable habitat were occupied by 5 June, but only 52 percent of the less suitable Kirtland's warbler locations were occupied by that date. By 5 June, 84 percent of the adult males were established, in contrast to 73 percent of the subadult males. Higher proportions of subadult males were in marginal habitat (44 percent) than in more suitable habitat (23 percent) in 1986. Only 8 percent of the males vacated territories by the end of June in suitable habitat, but 19 percent of the males abandoned territories in marginal habitat. These trends indicate that young birds have difficulty establishing territories in crowded, more suitable habitat, and may delay breeding because of their late arrival. Current research results suggest that stand colonization is affected by stand size and distance from occupied breeding areas, as would be expected from within-season dispersal.

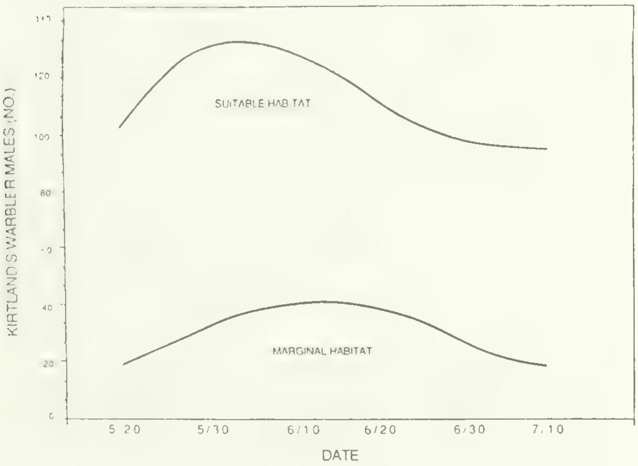

Figure 2.--Number of territories occupied by male Kirtland's warblers in marginal and suitable habitat during the 1987 breeding season. Trends were extrapolated to the entire known population (N=167 males) from a sample of males in suitable (N=58) and marginal (N=41) habitat.

In summary, habitat utilization by the Kirtland's warbler apparently is affected by both habitat quality and biogeography. Kirtland's warblers present a unique opportunity to study population regulation by habitat limitation because of their small breeding range, their concentration into 16-30 stands, and the facility of censusing their entire known population every year.

HABITAT MANAGEMENT

Kirtland's warbler land managers must supply a sufficient area of suitable habitat in the right locations to maintain a viable breeding population. Within management units, stand prescriptions should strive to maximize the number of breeding pairs for the entire period of occupancy. The highest possible production of fledglings from a stand will be achieved by maximizing the duration of occupancy without compromising the average annual breeding density. In most circumstances, this objective can be achieved by increasing the probability of early stand colonization and by extending the period a stand is suitable for new colonists. However, an anticipated habitat shortage may be alleviated by managing only for early occupancy (near-term shortage) or late occupancy (long-term shortage).

Large-scale Considerations

The area set aside for Kirtland's warbler management totals 51,700 ha in 16 areas owned by the State of Michigan (30,000 ha) and 7 areas owned by the USDA Forest Service (21,700 ha in the Huron-Manistee National Forest). This land is being managed on a 50-year Kirtland's warbler management and commercial timber rotation. The Recovery Plan calls for regenerating about 1,030 ha per year so that about 10 times that area is always suitably aged for Kirtland's warblers. If this habitat objective is maintained, an overall density of 3.8 males per 40 ha would achieve a viable population of 1,000 males. The average density in all occupied Kirtland's warbler habitat has been less than two males per 40 ha from 1981 to 1985 (Probst MS). If this density continues, the population would be about one-half the target figure. However, the future managed habitat could allow a higher average density of males. If 75 percent of the Kirtland's warbler habitat (10,340 ha) were occupied at five males per 40 ha, the objectives of the Kirtland's Warbler Recovery Plan developed for this Endangered Species could be attained. More than 6,100 ha of wildfire and plantation habitat should be available in 1993 to provide carrying capacity for 300 to 750 male Kirtland's warblers.

Clustering stands into 23 State and Federal management units with staggered scheduling of stand regeneration should minimize most biogeographic dispersal problems. Each management area will have to be large enough to support a population that is sufficient to maintain a colony during the 8 to 12 years a stand is suitably aged for Kirtland's warblers. For example, at a density of 3 males per 40 ha (data in Mayfield 1962), from 240 to 335 ha of habitat would be required to support about 20 males. When jack pine is managed on a 50-year commercial rotation, five such stands totalling from 1,200 to 1,600 ha would be needed for each management area. The majority of the 23 Kirtland's Warbler Management Areas (KWMA's) are more than 2,000 ha in size, so the minimum area should be present in most of them. The minimum habitat specified above assumes occasional recolonization from other management areas and regular colonization of young stands from adjacent occupied habitat.

The Kirtland's warbler is an early succession, area-sensitive species that is rarely found in stands smaller than 32 ha. The reasons for this minimum habitat size requirement are unclear, however, it appears that larger habitat patches support Kirtland's warblers for a longer time. This fact is probably related to both higher populations of Kirtland's warblers and the diversity of habitat patches generally present in larger areas. The current practice of managing contiguous blocks of more than 80 ha of similarly aged habitat should accommodate the habitat area requirement of the Kirtland's warbler.

Most adult migrant bird species (including Kirtland's warblers) return to the same breeding area each year (Berger and Radabaugh 1968, Greenwood and Harvey 1982, Walkinshaw 1983). Juvenile and yearling birds may stay on their natal grounds or disperse from there in late summer or the following spring. If few young birds randomly find habitat during migration, discovery of new habitat probably will be affected by distance from established breeding areas (see above). Thus, Kirtland's warbler habitat management should be directed primarily toward the current breeding range. Expanding the range should be attempted only near the periphery of the current range. Because establishing breeding populations is so difficult, it is imperative to keep each occupied KWMA close to its rotation schedule.

Landscape Design of Management Areas

Kirtland's warblers colonize taller and denser jack pine patches before they occupy habitat with shorter or less dense trees. It is possible to extend the period of Kirtland's warbler occupancy in a management area by several methods such as varying the timing of stand regeneration or the tree spacing in a plantation.

Current management guidelines prescribe maintaining 20 percent of each KWMA in each 10-year age class. Normally, cutting blocks are scheduled for harvest regularly throughout each 10-year period, but regeneration is not always on schedule. To ensure several years overlap in stand utilization by Kirtland's warblers, I emphasize that date of origin between cutting blocks should differ by about 5 years. This temporal overlap should make it unnecessary to maintain local populations by long-distance recolonization.

Site quality variability within a stand or unit can increase the period of occupancy by Kirtland's warblers because it creates a pattern of patches with varied foliage volume. Managers should be aware of the importance of this variety when scheduling planting or prescribing tree densities. For example, tree densities should be more uniform in areas with site variety because differences in height growth alone may provide the necessary variety in foliage volume without requiring tree stocking differences.

Although the Kirtland's warbler is an early-succession, area-sensitive species, little evidence has been found to relate Kirtland's warbler densities or productivity to stand shape and configuration. However, I hypothesize that at least two Kirtland's warbler nest predators -- red squirrel (Tamiasciurus hudsonicus) and blue jay (Cyanocitta cristata) -- may be less common in stands with trees shorter than about 4 m. It seems reasonable to assume that predation rates might be higher near edges of stands bordered by more mature trees. Thus, it would be prudent to avoid long, narrow stands to minimize such edges. A majority of stands managed for Kirtland's warbler in the recent past tend toward minimal edge.

Improving Habitat Quality

Most recommendations for improving Kirtland's warbler habitat center about increasing natural regeneration and optimizing tree spacing in plantations. Kirtland's warblers do not commonly colonize a stand until tree canopy cover exceeds 20 percent. Maximum male populations were recorded in stands with 40 to 60 percent canopy cover. Jack pine areas with 20 to 60 percent canopy cover have more than 6,250 stems per hectare in naturally regenerated stands and at least 2,700 stems per ha in plantations. However, plantations should have about 5,000 stems per hectare to attract colonists at the earliest possible stand age. This prescribed tree density is best achieved with a 1.3- by 2-m spacing pattern. A rectangular spacing pattern has more variety in the timing of thicket formation among the trees than a square pattern and should provide a longer period of Kirtland's warbler occupancy. Experimentation with opening sizes is needed. I suspect that openings should be smaller and more numerous than in past plantations where they averaged about 25 percent of the stand area.

Duration of Stand Occupancy. Recommendations for maintaining KWMA populations (above) stressed a variety of large habitat patches in both the temporal and spatial scales. The same strategy can be employed to extend the stand utilization period by Kirtland's warblers. The following seven alternatives are suggested to extend the length of stand occupancy:

1) Plantations with a variety of tree densities should attract Kirtland's warbler colonists both early and late in stand life. Experimentation with alternative tree densities is recommended. Because the Michigan Department of Natural Resources is currently using variable spacing of 1.3 by 1.3 m combined with 1.3 by 2.6 m, I recommend that the USDA Forest Service use 1.3 by 2 m and 1.7 by 2.3 m.

2) In stands with more than 1,250 stems per hectare of tree stocking, it may be feasible to plant dense 0.8- to 1.3-ha patches on 20 percent of a stand, and avoid the expense of full

(large-scale) planting.

3) It may be possible to regenerate dense 0.4- to 1.3-ha patches by leaving small clumps of standing mature jack pine during prescribed burns. (The Michigan Department of Natural Resources has had some success burning strip cuts in jack pine.)

4) In unburned areas lacking appreciable advance regeneration, a shelterwood cut followed by supplemental planting could provide high-quality habitat, but this would be more expensive than other options.

5) Plant from 20 to 30 percent of some stands with red pine at the same spacing as in item #1 above.

6) Large residual patches (greater than 15-m wide) of mature trees within wildfire areas may have advance regeneration that can be released by removing the overstory from 6 to 8 years after a burn. These patches could extend stand occupancy. Such areas have been used for nesting at Muskrat Lake Burn in Oscoda County, Michigan.

7) Very poorly stocked areas in burns greater than 8 ha could be fill-in planted about 5 or 6 years after the fire at 1.7 by 2-m spacing. Because the Mack Lake Burn has so much well-stocked habitat, additional planting should be delayed there until 1988 to 1992.

Kirtland's warblers require a dense layer of foliage from 0-1 m up to 1.7-4 m in height. If tree ages in a stand are too diverse, few thickets will be at the proper heights. Thus, fill-in planting should be scheduled before the existing trees are from 1- to 1.2-m tall. In some places the interplanted pines were established too late to affect habitat quality. This is especially true in cases where red pine was used as fill-in stock (see below).

Tree Species Other Than Jack Pine. Red pine is suitable for Kirtland's warbler plantations but not for fill-in planting. Red pine appears to have been beneficial to Kirtland's warblers in three stands because it extended their occupancy period by keeping live, lower foliage longer than jack pine. However, red pine can grow too slowly in the first 10 years on these poor sites and this can complicate scheduling considerations. Furthermore, red pine is more sensitive to microsite differences, and its growth is less predictable than jack pine. The slow, unpredictable early growth of red pine makes it unsuitable for fill-in planting. I recommend that managers experiment with planting red pine at densities prescribed for Kirtland's warbler on appropriate sites adjacent to KWMA's now managed for red pine.

The presence of northern pin oak Quercus ellipsoidalis), choke cherry (Prunus virginiana), or black cherry (P. serotina) may not be disadvantageous to Kirtland's warblers when dense jack pine thickets also are present. Broadleaf coppice is actively used for Kirtland's warbler foraging. In places where jack pine regeneration is marginal, oak sprout-growth should not be sprayed because it may help provide the minimum foliage volume required for Kirtland's warbler foraging. Kirtland's warblers have been found at high densities in stands (Damon Burn) with up to 20 percent oak (Smith 1979).

Snags and Residual Trees. Snags and residual trees that escape wildfire or harvest can be valuable song perches for Kirtland's warblers and are clearly beneficial where cowbirds are controlled. When cowbirds are not controlled, nest parasitism is higher near snags (Anderson and Storer 1976). Residual oak and pine trees are used for both singing and foraging. We have no data on the maximum volume of overstory tolerated by Kirtland's warblers, but the trees or stringers must be widely spaced or habitat will not be utilized. Overstory removals in Kirtland's warbler habitat are difficult to evaluate because habitat maturation always accompanies the removals. Scattered pine or oak residuals may be important in attracting the first males to a breeding area because some individual male Kirtland's warblers spend a majority of their time foraging in isolated trees, stringers, or the edges of mature forests. However, the scattered trees should probably not exceed 5 percent of the canopy.

Slash. Slash and logging debris are used extensively for Kirtland's warbler foraging. At present, we do not know how much logs and slash add to habitat quality and how much this use of debris as a foraging substate is strictly facultative. However, almost all foraging in openings or in dense ground cover is on logs, stumps, or slash, so managers should use caution when prescribing whole-tree harvesting on unburned stands. Removing most logging debris from unburned Kirtland's warbler stands will preclude a direct, incisive comparison of the suitability of unburned and prescribe-burned plantations. Therefore, I recommend that each Kirtland's warbler unit have at least one of its unburned cutting blocks harvested by conventional cutting.

Ground Cover Composition. Kirtland's warbler appear to accept most ground cover communities associated with dense jack pine stands on very poor sites. (The rejection by Kirtland's warblers of unburned stands with Carex sedges as a dominant ground cover is probably related to the open tree cover of stands with dominant Carex). If the ground cover requirements of the Kirtland's warbler are no more specific than a low, light cover of shrubs, grasses, and sedges, it should be possible to generate suitable habitat without fire (Table 1). If future patterns of habitat occupancy indicate a more specific ground cover requirement, steps can be taken to maintain or increase the xeric shrubs and/or retard ground cover succession on the better sites. Mechanical disturbance such as plowing or discing breaks up sod and low shrubs such as blueberry (Vaccinium sp.). This treatment is probably more effective than fire for altering ground cover composition. If optimal tree densities are achieved in unburned stands, shade should be sufficient to help favor shrubs over grass and sedge.

Table 1.--Prioritizing stands for prescribed burning.

Higher Priority Stands	Lower Priority Stands
1. Many residual jack pines	Significant advance regeneration
2. Abundant slash	Less slash, smaller residual trees
3. Better sites (>50 SI)	Poorer sites (<50 SI)
4. Dense broadleaf undergrowth	Low to moderate hardwood competition
5. No other site preparation anticipated	Good potential for "V-plow" planting or other heavy scarification
6. No fire history during last rotation	Recent history of fire

Natural Regeneration vs. Plantation

Much of the past focus on Kirtland's warbler habitat regeneration has revolved around the need for fire. The future focus should be on the need for natural regeneration on burned or unburned sites (Table 2). Natural regeneration will improve the quality of habitat even in the best stocked plantations. Where natural regeneration is excellent, planting costs can be reduced substantially. For suggestions on improving natural regeneration, see "Duration of Stand Occupancy" under "Improving Habitat Quality".

Seed tree burns have been unsuccessful at regenerating jack pine in Kirtland's warbler habitat. Unacceptable delays have occurred in planting warbler habitat because so few days are suitable for burning in a season. Prescribed fire has the potential to dramatically cut the costs of planting habitat, but safety concerns will have to be addressed. Fire's role in providing ground cover vegetation is complex, and prescribed fire could be used to create changes in vegetation. However, I believe the effects of fire on ground cover are short-term and can be duplicated more effectively with a variety of mechanical means.

Table 2.--Jack pine management options.

Harvest Option	Site Preparation	Regeneration[a/]
Strip-cuts	Prescribe burn Flow	Assess stocking Plant as needed between strips
Shelterwood	Burn and scarify	Assess stocking, plant as needed
	Scarify	Direct seeding Assess stocking
	Plow	Plant as needed
Seed tree	Burn and scarify	Direct seeding, assess stocking, plant as needed
	Roller - chop, plow	Full planting
Conventional clearcut	Roller - chop, plow	Full planting
Whole tree harvesting	Disc/harrow/plow	Full planting

[a/] Kirtland's warbler management requires denser stocking than timber management.

The preferred method for regenerating jack pine has been seed tree harvest followed by prescribed burning (Table 2). However, this prescription has not provided adequate natural regeneration, and almost all areas have been stocked by machine planting. Shelterwoods have been mostly unsatisfactory for full regeneration, and windthrows are a serious problem with this option. Future stand regeneration should be modified to achieve more natural tree regeneration. If successful, costs will be lowered, and habitat quality will be raised. Natural tree stocking can be increased by leaving more standing volume before prescribed burns (leave strips or >3.7-m^2 BA) or by using shelterwood where natural regeneration is insufficient.

The recommendations outlined in this paper were made after many years of research and management of Kirtland's warbler habitat. They can be used to improve habitat quality and breeding success. However, successful implementation of these management alternatives will require further experimentation and careful attention to scheduling of stand regeneration. Such an effort will only be possible with the continued cooperation of several government agencies, researchers, and the Kirtland's Warbler Recovery Team.

Many of the ideas presented in this paper were developed with foresters, wildlife managers, and members of the Kirtland's Warbler Recovery Team. I especially wish to thank G. W. Irvine, William Jarvis, David Sorenson, Jerome Weinrich, and the staff on the Huron-Manistee National Forest for their ideas about jack pine management for the benefit of Kirtland's warbler. Michael DeCapita, Cameron Kepler, Mark Nelson, Thomas Nicholls, Ronald Refsnider, Gustav Swanson, and Jerome Weinrich made helpful corrections to the manuscript.

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MANAGING NORTHERN FORESTS FOR BLACK BEARS[1]

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ABSTRACT.--Wild, radio-collared black bears (Ursus americanus) that became habituated to close (0-12 ft) observation by researchers showed activity patterns and habitat use patterns similar to those of radio-collared bears monitored from airplanes. The habituated bears were active mainly by day, sleeping from 1-3 hours after sunset until dawn with periodic naps through the day. Food, shade, security, and water were important habitat components. In early spring, the grass understory of forested wetlands provided the majority of food although these wetlands comprised <1% of the study area. Wetlands were also used for cooling. Dense thickets of balsam fir (Abies balsamea) saplings were preferred for shade. White pines (Pinus strobus) >20 in dbh located <200 yds from forested wetland feeding areas provided the majority of refuge trees for mothers with cubs in early spring although these trees comprised <1% of all trees >10 in dbh. Late spring diets included newly sprouting upland forbs, expanding aspen (Populus tremuloides) leaves, and ants. In summer, berries, nuts, ants, and forbs were major foods. Forest edges, mature forests, marshes and moist areas all contained major foods. The most important fall food is acorns. Management recommendations are included for each season.

INTRODUCTION

The original range of the black bear (Ursus americanus) coincided with forested regions throughout North America (Pelton 1982). That range has been reduced through forest removal or fragmentation and continues to be reduced by an expanding human population. However, extensive range remains, especially in northern or mountainous regions unsuitable for commercial agriculture. Many of these areas are managed for timber production, recreation, and wildlife, but more detailed information on bear habitat requirements is needed. A study was conducted to obtain habitat information that managers can integrate into resource management plans and use in opportunity area planning and implementation.

METHODS

Three methods were used to learn habitat needs of black bears in northeastern Minnesota. First, 83 radio-collared black bears were monitored to determine home range size and how the availability of certain forest types affects survival, growth, and reproduction (Rogers 1987a). Secondly, more

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than 1,200 fecal scats were examined to determine differences in diet between years when bears thrived and years when their growth and reproduction were poor. Habitats that produced the foods identified in the scats were then studied to determine what forestry practices led to those habitats being productive (Arimond 1979). Thirdly, current studies involve observing four wild, free-ranging, radio-collared black bears that are habituated to observers.

The habituated bears, who allowed observers to record data from within 4 yards for 24 hours at a time, showed movement and activity patterns similar to those of bears radio-tracked remotely. Although aware of the observers, the habituated bears paid little attention to them. The bears foraged and napped by day and slept at night as has been reported for other bears (Rogers 1987a). Mothers tended and nursed their cubs, and the cubs showed normal growth.

Data recorded from habituated bears included: habitat type, amount eaten of each food in each habitat, number of minutes spent on each activity in each habitat, and reactions to insects, weather, other bears, and other animals. Each of the three methods (radio-tracking, scat analysis, direct observation) provided unique but complementary information. Continuing study will involve further observation of habituated bears.

STUDY AREA

The studies were conducted in the Superior National Forest in northeastern Minnesota. The study area is approximately one-fourth lowland and three-fourths upland, with upland mixed coniferous-deciduous forest communities predominating (Peek et al. 1976). Vegetation is typical of the northern Great Lakes region, containing components of both the boreal forest and the temperate deciduous forest (Maycock and Curtis 1960). Common upland trees are aspen (Populus tremuloides, P. grandidentata), paper birch (Betula papyrifera), red pine (Pinus resinosa), white pine (P. strobus), jack pine (P. banksiana), white spruce (Picea glauca), and balsam fir (Abies balsamea). Common lowland trees are black spruce (P. mariana), balsam fir, tamarack (Larix laricina), white cedar (Thuja occidentalis), black ash (Fraxinus nigra), and paper birch. Soils are noncalcareous sands and gravels and are often shallow, especially northward where rock outcrops are common on the Laurentian Shield (Minnesota Soil Atlas 1981). Glacial deposits tend to be deeper and more loamy southward toward Lake Superior and beyond (Wright and Watts 1969, Ojakangas and Matsch (1982).

BEAR MOVEMENTS

Radio-tracking revealed that black bears in northeastern Minnesota use larger areas than bears elsewhere (Rogers 1987b), probably due to the low fertility of the area (Rogers 1987a). Adult females maintained territories averaging 2.5 miles in diameter, and males concentrated their activities in ranges averaging 7.5 miles in diameter. These ranges are not unusually large, but 40% of the females (N=105) and 69% of the males (N=32) ranged 4-125 miles outside those areas in late summer and fall before returning to their usual areas for denning (Rogers 1987a). Most (70%) of the long movements (N=66) were to areas of deeper, more loamy soil and greater fruit and nut production than in the main study area.

SPRING HABITAT USE

Bears emerged from their dens when the weather turned warm enough in late March or April, but most remained lethargic until late April or early May when aspen catkins and green vegetation became available (Rogers 1987a). Swamp grasses, especially bluejoint reedgrass (Calamagrostis canadensis) and fowl mannagrass (Glyceria striata) were major foods in early spring. These species were found in the understories of tamarack swamps, alder (Alnus rugosa) swamps, and especially back ash swamps. In the spring of 1987, unusually low water levels increased bear access to swamp grass. The bears concentrated their feeding in ash swamps even though that cover type constituted <1% of the study area.

As upland forbs emerged, bears in the study area added large-leafed aster (Aster macrophyllus), false lily-of-the-valley (Mainanthemum canadensis), smooth bedstraw (Galium triflorum), interrupted fern (Osmunda claytonia), and peavine (Lathyrus spp.) to their diets but ceased eating all but peavine when the leaves reached full size. As wild calla (Calla palustris) and jewelweed (Impatiens capensis) began to emerge, bears added these wetland and lowland plants to their diets and continued to eat them through summer. In other northern forests, jack-in-the-pulpit (Arisaema triphyllum) corms and young skunk cabbage (Symplocarpus foetidus) leaves are important spring foods (Elowe 1984, W. Breckenridge, pers, commun.), further indicating the importance of forested wetlands and lowlands to black bears. Most of the feeding on upland forbs by habituated bears was in the vicinity of ash swamps that they continued to use through May.

The presence of large pines appeared to be a major determinant of habitat selection in spring, especially by mothers with cubs. Nearly all the feeding by a mother with cubs was within 200 yards of white pines >20 inches dbh, which she used as refuges for her resting cubs. Elowe (1984, 1987) found that mothers with cubs in Massachusetts centered their spring activities around large white pines and hemlocks in the vicinities of forested wetlands. Both white pines and hemlocks have rough, strong bark suitable for climbing by cubs. Cubs have been observed falling from aspen trees, spruce trees, and young red pines because their claws slipped on the smooth or flaky bark (Rogers and Wilker, unpubl. data). At least one death from a fall has been reported (Elowe 1987). Where large white pines and forested wetlands were near lightly traveled roads, the bears fed heavily on roadside dandelion (Taraxaum officinale), red clover (Trifolium pratense), and peavine in mid-May.

During May, ants surfaced and became part of the diet. By late May, ant pupae become abundant in the colonies while most upland forbs reached full size and were rejected. Ants, primarily carpenter ants (Camponotus spp.) in logs and stumps in open areas, then became the primary food until fruit ripened in early July. Most of the logs were from balsam fir trees that had been killed by spruce budworms (Choristoneura fumiferana) 1-2 decades earlier (Hardy et al. 1986). Logs in forest openings tended to hold the most ants.

SUMMER HABITAT USE

Fruit and hazelnuts (Corylus cornuta) were preferred summer foods and the major determinants of weight gain, reproductive rate, and cub survival for northeastern Minnesota bears (Rogers 1976, 1987a). Young females typically did not produce their first litters until after a year of abundant fruit and nuts; some females failed to reproduce until 8 years of age (average 6.3 years) (Rogers 1987a).

Under ideal food conditions, reproduction begins at 3-4 years of age (Alt 1980, Kordek and Lindzey 1980). Cub survival (N=11 years, 181 cubs) ranged from 59% to 88%, depending upon fruit and nut production in the year of conception and the first year of post-partum life (Rogers 1987a).

Important fruits in northeastern Minnesota were wild sarsaparilla berries (Aralia nudicaulis), cherries (Prunus virginianus, P. pensylvanicus), blueberries (Vaccinium angustifolium, V. myrtilloides), serviceberries (Amelanchier spp.), dogwood berries (Cornus rugosa, C. stolonifera), raspberries (Rubus strigosus), and mountain-ash berries (Sorbus spp.). In other northern forests, feral apples (Pyrus malus), buffalo berries (Shepherdia canadensis), black cherries (Prunus serotina), and blackberries (Rubus spp.) are also important summer foods (Elowe 1984, Bertagnoli 1986).

Few black bear foods (e.g., wild sarsaparilla berries and hazelnuts) are shade tolerant species. Black cherry and oak are forest canopy species but require openings for regeneration. Most fruit producing species require much sunlight for maximum production. In northeastern Minnesota, blueberry, raspberry, and cherry (P. virginianus, P. pensylvanicus) production varied inversely with tree density during a 4-year study of 29 unburned sites (Table 1) (Arimond 1979).

Table 1. Combined production of blueberries, cherries, and raspberries in stands of different tree density in northeastern Minnesota, 1974-1977 (from Arimond 1979).

Trees/acre	No.	Average fruit production	
	Stands	lbs/acre	Range(lbs/acre
Few or none	8	80	11-194
192-311	9	12	0-101
418-480	6	5	0-32
511-848	6	<1	0-3

The only burned site studied was more productive than any of the unburned sites; blueberry production averaged 318 lbs/acre during 1974-1977 (Arimond 1979). Two sites treated with 2,4-D produced only raspberries for the 3-4 years of study after treatment (Arimond 1979).

Forest openings such as burns, clearcuts, select cut areas, edges of rock outcrops, old homesteads, marsh edges, insect damaged areas, untraveled roadsides, power line rights-of-way, and old growth forests with numerous windfall openings are favored feeding areas in summers with good berry crops because these areas have the right amount of sunlight to stimulate berry production. Plants with no tree cover in southeastern Manitoba were found to experience greater frost damage and a less favorable water economy than plants under partial shade, with consequent lower productivity (Hoefs and Shay 1981). This may partly explain why feeding in large openings is concentrated near the edges where understory vegetation may be protected from thermal extremes. Black bears may also avoid the centers of large openings because of the absence of shade and escape cover (Jonkel and Cowan 1971). Black bears are easily heat-stressed in full sunlight (Rogers, unpublished data). McCollum (1973) found a dramatic decline in use of clearcuts beyond 200 yards of forest cover. Hugie (1982) reported little use beyond 135 yards of forest cover.

In a black cherry stand in Michigan, >90% of the fecal droppings of bears were within 10 feet of scattered, large (>10 inch dbh) hemlock trees (Rogers, unpubl. data). Elowe (pers. commun.) observed similar use of large hemlocks in New England. This suggests that refuge trees influence habitat use even within forest habitat in summer.

Although upland openings are favored feeding sites in summers with good berry crops (or mature upland stands when wild sarsaparilla berries are abundant), bears seek other habitats in years when berry crops fail. In 1987, when berries were scarce, a habituated female obtained much of her food in July and early August from alder and tamarack swamps where she ate wild calla and jewelweed. Other feeding sites were along seldom traveled forest roadsides, where she ate clover (Trifolium spp.) and wild lettuce (Lactuca spp.), and in mature upland spruce stands, where she ate bunchberries (Cornus canadensis). In early August, hazelnuts ripened and became her primary food from mid-August until they disappeared. During this period, she foraged far outside her territory, finding a productive hazel stand 22 miles away. She fed mainly in a 5 acre area there for 22 days, eating 2,605 hazelnuts in 24 hours on 27-28 August. The hazelnuts disappeared from that stand during the next week, and the bear started home. She arrived home on 7 September after pausing 2 days enroute in a round-leafed dogwood stand.

FALL HABITAT USE

Probably the greatest habitat deficiency in northeastern Minnesota and other forests north of Lake Superior is the paucity of nutritious fall foods. Hazelnuts, ants, and most species of berries become scarce in September. Bears then must turn to vegetation such as clover and peavine (or, in some years, to hornets) and begin losing weight. Acorn producing oak stands (primarily northern red oak, Quercus rubra) are uncommon, constituting <0.05% of the region. Bears that find the few oak stands show superior growth and reproduction because acorns allow them to extend their annual growth period into fall. Black bears can learn the locations of mature oak stands and pass this information on to their offspring (Garshelis and Pelton 1981, Rogers 1987a). A bear clan with a tradition of traveling 22 miles to an oak stand each fall showed the greatest weight gains and the highest reproductive rate observed in northeastern Minnesota among bears that ate only natural food (Rogers 1987a). A young female in this clan was the only study female to reproduce by 4 years of age without having access to garbage (Rogers 1987a).

South and east of Lake Superior, more fall foods are available due to a greater variety and prevalence of oak species, the presence of beech (Fagus grandifolia), and a more common occurrence of feral apples. However, even in those areas, northern red oak is the primary producer of fall mast.

DENNING HABITAT

Black bears in the northern Great Lakes Region commonly spend 4-7 months a year in dens. They enter dens between September and December, depending upon regional norms of food availability, and leave them between late March and early May, depending upon spring thaws and the presence of cubs (Rogers 1987a). Cubs are born in January every other year if nutrition is adequate or less often if the mothers are unable to gain sufficient weight in summer and fall (Rogers 1987a).

Preferred maternal dens are tree cavities (Jonkel and Cowan 1971, Johnson et al. 1978, Lentz 1980, Lentz et al. 1980, Rogers 1987a). These provide good thermal protection and reduce vulnerability to predation, human disturbance, harassment by dogs, and flooding by rain or meltwater. Cubs depend upon their mothers for warmth and will die if dens are flooded or mothers are disturbed and forced to leave the cubs for long (Smith 1946, Johnson and Pelton 1980, Alt 1984). However, tree dens are less critical in northern habitats than they are farther south where winter thaws and disturbance are more likely. In northeastern Minnesota, where most forests are second growth with few trees large enough to have suitable cavities, bears used burrows, rock crevices, brush piles, rock-raked windrows, and surface nests (Rogers 1987a). Winter thaws there were not sufficient to flood dens, and few people other than loggers used the forest in winter. One family of bears was killed and eaten by wolves (Canis lupus), but this was the only predation to occur during overwinter observations of 206 occupied dens (Rogers and Mech 1981). Overwinter survival was >99%. Denning habitat did not appear to be a critical habitat feature in that area.

BLACK BEAR HABITAT MANAGEMENT

Probably the most important consideration for maintaining black bear habitat is maintaining large enough blocks of diverse forested land with few enough permanent human residents that black bears can reproduce faster than they are killed. More than 90% of the mortality among black bears (N=35) that reached the age of independence (1.5 years) in northeastern Minnesota was from human-related causes, primarily bullets (Rogers 1987a). Hunting deaths are not considered a long-term threat because those deaths can be regulated through game regulations, but the killing of nuisance bears by permanent human residents is unregulated, and the presence of permanent residents can reduce population viability. The lower the land fertility or the higher the permanent human population, the more land will be required to maintain a viable population of bears (Rogers and Allen 1987). Another factor in bear survival is human attitudes. Black bears in Wisconsin and Pennsylvania coexist with higher human populations than in northeastern Minnesota due to lower poaching/nuisance losses. Thus, education may ameliorate problems of high human density (Rogers and Allen 1987).

Although bear density strongly depends upon human tolerance, reproductive success of adult females and survival of cubs through 1.5 years of age depend primarily upon food supply. Consequently, silvicultural prescriptions should be oriented toward increasing production and diversity of food species, especially fruit and nut producing species. One of the most effective actions a forest manager can take to maintain bear habitat is to maintain mature stands of oak where these are scarce. Within the Superior National Forest, oak cutting is now banned except for regeneration cuts (E. Lindquist, pers. commun. 1987). Outside the Forest, some of the scarce, mature, red oak stands have been cut for firewood, significantly reducing habitat quality for black bears and other species.

Once a red oak stand is lost, it is difficult to reestablish without specific management toward that goal (R. Jacobs, pers. commun.). Time to full maturity is long. Northern red oak begins to fruit when approximately 25 years old but does not produce abundant acorns until 50 years of age (Fowells 1965). Some acorns then are produced each year with good crops every 2 to 5 years for 100 years or longer (Fowells 1965, Elias 1980). Production may maximize at 20-22 inches dbh and decline with decreasing size, according to a study in the southern portion of the species' range (Downs and McQuilkin 1944). A 10 inch dbh tree may produce 0.4 lbs of acorns/year, a 14 inch dbh tree may produce 15.8 lbs/yr (Shaw 1970). A fully stocked mature stand would be expected to include 70-90 square feet/acre basal area of mature trees, 15 square feet/acre of pole-sized trees, and 5 square feet/acre of smaller trees.

Maintaining mature stands of other locally scarce, food producing trees such as mountain-ash (Sorbus spp.), black cherry, feral apples, wild plum (Prunus spp.), and beech is also beneficial. Most other fruit or mast producing species of northern forests are shrubs or forbs and tend to be more common. Many of these understory species are shade intolerant, and their fruit production can be enhanced by thinning the overstory, as has been shown in Washington (Lindzey and Meslow 1977), Montana (Jonkel and Cowan 1971), Michigan (Manville 1983) and Minnesota (Arimond 1979) (Table 1). However, thinning of commercial stands can severely damage established shrub species; therefore, an effort should be made to minimize damage to ground species. Prescribed burning (Arimond 1979, Gruell 1980) and curtailing of grazing can also improve productivity of fruit and mast producing species. Containerized plantings or seeding in favorable sites may increase distribution (Irwin and Hammond 1985). The value of forest openings to bears and other omnivores can be further enhanced by plantings of legumes (Trifolium spp., Vicia spp., Lathyrus spp.) (Jonkel and Cowan 1971:21).

Clearcuts may be beneficial or detrimental depending upon their size, configuration, and herbicide treatment. Benefits of clearcuts decrease with increasing size because of the reluctance of bears to move far from forest cover (Young 1980). Islands or peninsulas of forest cover in clearcuts can increase use of surrounding open areas (Lindzey and Meslow 1977), especially by mothers with cubs due to their greater reluctance to leave forest cover (Herrero 1979). Broadcast application of herbicide can kill all the major fruit and mast producing species of the northeastern United States. Reestablishing those species requires 4-10 years or more (Arimond 1979, Rogers, unpubl. data). However, hand application of herbicide allows survival of berry producing species and enhances fruit production under the opened canopy (McComb and Hurst 1987). Logs from herbicided trees can become suitable for ant colonies within 10 years (Rogers and Wilker, unpubl. data). Several researchers found that bears avoided clearcuts for approximately 10 years after timber harvest but favored them after that interval (Jonkel and Cowan 1971, Lindzey and Meslow 1977, Kellyhouse 1980). Whether this initial period of avoidance was due to lack of shade and escape cover, reduced food supply as a result of herbicide treatment, or other factors is unknown.

Forested or shrub wetlands with understories of bluejoint reedgrass, fowl mannagrass, or wild calla are important spring and summer feeding areas but are commonly distributed in such small patches (<2 acres) that they often are not delineated on survey maps and are consequently clearcut along with surrounding stands. Where such wetlands constitute less than 45 acres per square mile (7% of the area [Elowe 1984]), uncut buffer zones of 200 yard radius would help maintain the wetlands and the surrounding high use uplands for black bears, wood ducks (Aix sponsa), white-tailed deer (Odocoileus virginianus), muskrats (Ondatra zibethicus), and other herbivores (Martin et al. 1951, Elowe 1984, Rogers and Allen 1987). Minimizing disturbances of wetlands in spring when they receive greatest use will further benefit these species.

Habitat selection by mothers with cubs, and perhaps by other bears, partially depends upon the presence of white pines or hemlocks >12 inches dbh, especially in spring. The presence of at least one of these trees per 10 acres (65/square mile) in and around feeding areas would enhance habitat quality for black bears. This spacing is based on the assumption that bears will feed up to 200 yards from each tree (Rogers and Wilker, unpubl. data; Elowe 1987). However, additional refuge trees may be beneficial, especially around forested wetlands used in spring when cubs are small. In observed feeding areas with several refuge trees per acre, nearly all refuge trees were used, even in late summer feeding areas.

In summary, silvicultural prescriptions should be oriented toward increasing production and diversity of food species. Black bears depend upon a diversity of foods, particularly in northern areas where fruit and mast crops frequently fail due to extreme weather. A diversity of foods, including a diversity of fruit and nut species, increases the likelihood of an adequate food supply due to differences in the times of flowering and fruiting of the different species. Of utmost importance in the maintenance of bear habitat is maintaining adequate space. The wide-ranging habits of black bears and their attraction to people's food make this species one of the first to be extirpated when forests are reduced or fragmented by the expanding human population. State and National Forests tend to be less fertile than the forests that covered much of the black bear's original range. The amount of land in those forests is sufficient, with proper management, to insure viable populations of black bears for the foreseeable future.

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RIVERS OF SAND: RESTORATION OF FISH HABITAT ON THE HIAWATHA NATIONAL FOREST[1]

Charles E. Bassett[2]

ABSTRACT.--Logging practices of the late 1800's and early 1900's profoundly damaged fish habitat in rivers of northern Michigan. Huge inputs of sand and removal of large woody debris were the primary causes of habitat degradation. Detrimental effects persist to the present day and will not diminish soon unless habitat restoration is actively pursued. Habitat restoration goals on the Hiawatha National Forest are: eliminate major point sources of sand input; remove sand accumulations from river channels; manage riparian vegetation to provide required amounts of large woody debris; and install organic structure and rock spawning habitat where other methods will not provide an adequate fishery in the short-term. Specific techniques are summarized.

INTRODUCTION

Fisheries inventory has shown that unstable sand substrate, severe bank erosion and meager amounts of large woody debris are typical of many rivers on the Hiawatha National Forest (HNF) in Michigan's Upper Peninsula. Salmonid populations in these rivers are low despite favorable water temperature and chemistry. Similar conditions occur on the Huron-Manistee National Forests in the Lower Peninsula of Michigan.

The perception that these conditions are "natural" is common among river users. This stems from the fact that most efforts to find documentation of the pre-logging condition of North American rivers have occurred within the past 10 years. Consequently, public perception of acceptable resource condition is largely based on what people have experienced in their own lifetime. They assume that northern Michigan rivers always were full of sand and always had numerous eroding banks. For the same reason, scarcity of large woody debris in rivers is considered to be a normal condition. It follows that attempts to increase fish populations by adding woody structure and stabilizing eroding banks have been viewed as enhancement of a natural situation.

Evidence from several sources indicates that rivers on the HNF were not always in the present condition. Fisheries workers found extensive deposits of gravel and cobblestone buried under 2-4 feet of sand. A sawlog bearing the stamp of a timber company that operated in the 1890's was found under 5 feet of sand in a riverbed. These discoveries led to study of old logging photos, historical accounts of pre-logging conditions and early logging practices, as well as recent research dealing with the impacts of historical logging on fish habitat. Together these sources led to the conclusion that HNF rivers were severely damaged by early logging practices and that habitat degradation persists to the present day.

Presented herein is evidence to support this conclusion. Much of the evidence is circumstantial and there is some extrapolation of data from other parts of the country to rivers of the HNF. Further study may show that some of the inferences made are wrong. None-the-less, there appears to be ample evidence that many fisheries activities, traditionally called habitat "enhancement", are actually habitat restoration.

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PRE-LOGGING CONDITIONS

Descriptions in journals of early surveyors, loggers, and fishermen reveal that large accumulations of fallen trees was a dominant characteristic of northern Michigan rivers prior to logging activity (Williams, 1880; Buttars, 1918; Northrup, 1958). Large pines and dense stands of cedar grew on the banks of most rivers. In some places, rivers were so completely covered with huge rafts of woody debris, on which vegetation had taken root, that no water could be seen (Leach, 1903). The slow decomposition rate of submerged pine and cedar contributed to the longevity and size of these debris jams.

In contrast to the frequent references to woody debris in rivers, early accounts made no reference to bank erosion. While not conclusive, this suggests that severe bank erosion was unusual in northern Michigan prior to the mid-1800's.

Rivers throughout northern Michigan supported large populations of resident and migratory fish. The grayling was the dominant resident gamefish in northern Lower Michigan while brook trout and grayling occurred in Upper Michigan (Mershon, 1923). The prolific grayling attracted the attention of wealthy, eastern anglers as early as the 1860's (Norris, 1883). Daily catches of 50-100 grayling, averaging 0.3 pounds, were not unusual for the skillful angler (Northrup, 1958). Spawning runs of walleye, lake sturgeon, whitefish and lake trout from the Great Lakes ascended the lower reaches of many Michigan rivers (Lawrie and Rahrer, 1972; Smith, 1972; Wells and McLain, 1972; Bertrand et al., 1976). These runs were an important source of sustenance for early European settlers and native Americans. The name of the Sturgeon River on the HNF reflects the past occurrence of lake sturgeon in that system. Sturgeon bones were found at a prehistory archaeological site on the river and the name of the village at the river mouth ("Nahma") means sturgeon in the local native-American language (John Franzen, Forest Archaeologist, personal communication). Names of other HNF rivers such as the Whitefish and Fishdam may reflect the early abundance of lake-run fish in these systems. In general, northern Michigan rivers offered diverse, productive fisheries prior to about 1880.

LOGGING PRACTICES

Initiation of most logging activities in northern Michigan occurred between 1850 and 1880 (Karamanski, 1984). The huge white pines and cedar offered what appeared to be an unlimited supply of building materials for midwestern towns and industries. By 1900, approximately 25 billion board feet of pine had been cut from the forests of Upper Michigan (Maybee, 1960). All of the trees were cut by hand, removed from the forests by horses pulling "big wheels" and transported to market by steam power or river drive.

After establishing a sawmill near the rivermouth, the difficult task of clearing the river began so that logs could be floated downstream (Leach, 1903). Fallen trees, debris jams and obstructions of any kind were removed. Failure to remove obstructions resulted in log jams that were expensive and dangerous to break up (Brown, 1936; Karamanski, 1984). Logs were rolled down riverbanks and into the water. High, steep banks that allowed logs to roll directly into rivers were favored "rollways".

When the timber supply had been exhausted along the larger rivers, loggers moved up the tributaries. On streams too small to readily float logs, a system of splash dams was constructed to provide ponds for holding logs. When the pond was full of logs the dam was opened ("splashed"), flushing its contents to the next pond downstream and so on until a larger river was encountered (Sedell et al., 1982). Most wooden components of splash dams have rotted away but the presence of earthen dikes on streams as small as 10 feet wide, indicates that few HNF streams escaped the effects of logging (Karamanski, 1984).

LOGGING EFFECTS

Fish habitat was not a concern at the time when rivers were being prepared for log transportation (Sedell et.al., 1982). Angling for sport was almost exclusively a pursuit of a few adventurous, wealthy individuals who could afford to move to virgin waters when logging and other abuses depleted fish stocks closer to population centers (Northrup, 1958). The conservation ethic, later championed by Gifford Pinchot and Teddy Roosevelt, did not yet influence natural resources management decisions.

This situation resulted in poor documentation of the effects of logging on fish habitat. Logging era photos are as helpful as the few written accounts in revealing effects of logging on the aquatic resource in northern Michigan.

Removal of large woody debris (LWD) to facilitate log drives was the first major abuse to fish habitat. In a review paper, Sedell et al. (1984) summarize a considerable amount of recent research documenting the importance of LWD for creating and maintaining productive fish habitat. Current scouring around LWD creates pools and maintains spawning gravel free of sediment. Large woody debris provides hiding and feeding areas for fish and is important as an attachment site for invertebrates that fish feed on. On high-gradient bedrock streams, LWD traps gravel that would be swept away otherwise. Large woody debris provides critical overwintering habitat for juvenile salmonids. Removal of LWD causes instability in channel morphology that adversely impacts fish populations. It is readily apparent that removal of LWD by early loggers would have resulted in significant fishery losses even if no other abuses had occurred. Harvest of riparian timber eliminated the future source of woody debris for many decades. Even where the original timber species have regenerated, few have matured sufficiently to replenish the supply of LWD that was removed.

Another effect of logging activities was increased sediment input to rivers. Repeated scouring by thousands of logs, pushed along by high flows from splash dam releases, stripped vegetation from the sand banks. The combined practices of rolling logs down steep banks and log driving resulted in substantial channel widening (Brown, 1936). Historical photos of Bill's Creek, a tributary to the Whitefish River on the HNF, show that the channel was over twice as wide about 1900 as it is today.

Other photos of river drives on the HNF indicate that severe bank erosion was the rule rather than the exception where rivers abutted steep sand banks. Comparison of present riverbank conditions with those shown in historical photos suggest that these rivers are slowly returning to an equilibrium state where bank erosion is much less common. Today, there are many banks in various stages of healing. Many of the remaining sites of severe bank erosion on the Huron-Manistee National Forest were once used as log rollways (Ron Dunlop, Forest Fisheries Biologist, personal communication). On the HNF erosion is most severe where logging impacted the most infertile sand soils.

Fires that followed logging compounded the erosion problem immensely. For every 3 trees cut in northern Michigan 5 burned (Wendell Hoover, Michigan DNR Park Interpreter, personal communication). Old photos show stumps with roots completely exposed because the upper, organic layers of the soil had burned away. Loss of soil nutrients and moisture holding capacity are responsible for the persistence of sparsely vegetated stump meadows across northern Michigan today.

Research has shown that increased streamflows resulting from present day timber harvest operations are not adequate to immediately transport all of the increased sediment load that is generated. Streamflow volumes typically increase 10-80 percent but sediment loads often increase 1000 percent or more (Cordone and Kelley; 1961; Reinhart et al., 1963; Fredriksen, 1970; Verry, 1986). Therefore, it seems likely that the net effect of over 50 years of logging and fires was a substantial accumulation of sand in river channels.

Alexander and Hansen (1983) found that important components of fish habitat including pools, undercut banks and gravel deposits, are lost as a result of moderate increases in sand bedload. Water surface elevation increases in the stream channel and in the riparian water table. High water table discourages regeneration of many native timber species but favors dense growths of speckled alder. This explains the presence of old pine and cedar stumps in many alder stands.

Alder is inferior to native timber species for providing LWD because stem diameter rarely exceeds 4 inches. Alder is also undesirable because it tends to slump into streams producing frequent, mid-channel accumulations of small debris that is easily moved by high flows. The result is wide, shallow streams that lack well-developed pools.

Evidence that sand generated by pre-1900 logging and fires could still affect northern Michigan rivers is provided by a study that documented the rate of sand movement through a stream. In the study done by Alexander and Hansen (1983) sand was continuously added to a northern Michigan trout stream for 5 years. The bedload created was no higher than occurs naturally in several area rivers. It took 21 months for sand to move one mile through the study area. Sand accumulations persisted in the stream channel for 4 years after all inputs were ended. There had been little recovery of deep pool habitat by the end of the 4 year post-treatment period. Chronic sand inputs from eroding banks and roads contribute to the persistence of sand in rivers.

Even slightly elevated sand bedloads substantially reduce trout populations. A 17 parts per million (ppm) increase in sand bedload results in a 10 pounds per acre decline in trout populations (Alexander and Hansen, 1983). Many HNF rivers have sand bedloads of 30-80 ppm indicating considerable potential for improvement through sand control.

Splash dams damaged fisheries by blocking spawning migrations of resident and lake-run fish (Bertrand et al., 1976; Sedell et al., 1982). Release of log-laden water from dams in the spring resulted in sedimentation and scouring of the spawning habitat of grayling which became extinct in the early 1900's (Peterson, 1958). The combination of dams, increased sediment loads and sawdust in rivers contributed to the loss of river-running stocks of whitefish and lake trout as well (Bertrand et al., 1976; Smith, 1972). Michigan Department of Natural Resources records show no recovery of whitefish and lake trout runs and runs of walleye and lake sturgeon are meager or non-existent across most of their former range.

RIVER RESTORATION PROGRAM

Based on the evidence that rivers have not recovered from effects of early logging, the HNF developed a river restoration program having four primary goals: 1) eliminate point sources of sediment input to rivers; 2) reduce sand accumulations in river channels; 3) manage riparian timber stands to provide a sustained yield of LWD; and 4) install woody structure and gravel suitable for fish spawning where other methods will not provide an adequate fishery in the short-term. These goals are reviewed individually.

Eroding banks and roads are significant point sources of sediment entering HNF rivers. Forest hydrologists determined that eroding sand banks on the Indian River in Schoolcraft County contributed approximately 0.1 cubic yards of sand per lineal foot of bank annually (unpublished data). Stabilization of 2000 lineal feet of bank on this river since 1979 has eliminated the equivalent of about 20 truckloads of sand from this river each year. The stabilization process consists of placing 12-24-inch rock along the toe of the bank, sloping the upper bank to an angle at which it will remain stable, then applying topsoil, seed and mulch. Sod from the surrounding area is mixed with the topsoil to speed establishment of native forbes and shrubs.

Runoff from the surface of gravel and sand roads contributes to sediment loads where approaches to rivers are long and steep. Typical grading practices create a berm along each side of the road. This traps most of the sediment-laden runoff on the road surface until it reaches the low point of the road which is usually directly over the river. This problem is being addressed by removing the berm and constructing lateral ditches that direct runoff into vegetated areas away from the river. Options such as paving approaches to rivers and use of longer culverts to minimize direct entry of graded road materials into rivers are now routinely considered when planning road construction and reconstruction jobs.

Treating point sources of sand does not quickly eliminate sand accumulations from rivers. Sediment basins, excavated in river channels, are a quick, effective means of removing sand accumulations. Low current velocity in the basin allows transported sand to settle out of suspension. As a result, sand accumulated in the channel downstream from the basin flushes out, exposing gravel and woody debris. A series of basins spaced along a river system eliminates accumulated sand much more quickly than would natural processes.

The typical basin is 200 feet long, 20 feet wide and 6 feet deep but size varies considerably depending on size of stream and amount of sand input expected. Basin dimensions are based on guidelines developed by Hansen (1973). Most basins fill and have to be cleaned out once every 2-4 years. Usually, spoil is spread immediately adjacent to the basin as specified by the Michigan Department of Natural Resources and the Forest Landscape Architect. Spoil sites are selected to minimize impacts on wetlands and floodplains. In visually sensitive areas, topsoil is spread over sandy spoil prior to seeding to speed revegetation. Establishment of clover and other plant species attractive to wildlife creates dual benefits from these projects. Benefits to salmonid habitat and populations in Lower Michigan have been well-documented by Hansen et al. (1982) and Alexander and Hansen (1982). Preliminary monitoring results indicate that a similar response is occurring on the HNF (unpublished data).

Efforts to manage riparian timber on the HNF are directed toward converting alder to long-lived timber species and developing standards and guidelines that will assure adequate recruitment of LWD to rivers. Conversion to native cedar and spruce is accomplished by removing alder from strips averaging 25 feet wide along one or both banks. Removal is done by hand-cutting at ground level followed by hand-spraying of an appropriate herbicide to stump sprouts in June of the year after cutting. Cedar and spruce nursery stock is scatter-planted through the resulting meadows except where small openings are desired to enhance wildlife habitat. Alder removal alone substantially improves trout populations on some small streams (Hunt, 1979). However, other habitat manipulations must be done in addition to alder removal to gain a favorable population response elsewhere. Alder removal is a first step towards a long-term vegetative goal.

Guidelines for management of riparian timber stands on the HNF call for management that will recruit and maintain in the river at least one 12-inch diameter tree per 100 lineal feet of channel. This guideline is considered to be very preliminary as it is based on personal observations and some western research (Rainville et al., 1985). The traditional practice of leaving buffer strips along HNF streams has encouraged recovery of riparian stands.

Immediate demand for improved fisheries is met by a wide variety of habitat structures. Woody structure is provided by log bank covers, deflectors, half-logs, K-dams, tree drops and other devices which have been thoroughly described in numerous publications (White and Brynildson, 1967; Seehorn, 1985; Hunt, in press). In contrast, construction of spawning habitat in eastern streams has not been well-documented. The HNF has installed over 3400 square yards of spawning habitat for resident and anadromous salmonids. Some of these structures accommodate spawning lake sturgeon and walleye as well. Populations of juvenile salmonids have increased as much as 30-fold following installation of spawning gravel (unpublished data, Fishdam River).

Spawning areas are made by armoring each bank with cobblestone which prevents bank erosion, then installing a gravel layer 8-24 inches thick on the streambed. Low rock sills spaced 3-5 channel widths apart along the structure produce hydraulic conditions that encourage spawning activity. Placement of woody structure on the spawning area results in heavier use. Most spawning areas are constructed immediately downstream from a sediment basin.

CONCLUSION

The effects of early logging in northern Michigan will persist for many more decades unless managers actively pursue habitat restoration. Faced with growing demand for fish and wildlife outputs, National Forests can not afford to have aquatic systems operating at less than full capability. Cooperation with State and private organizations and interdisciplinary project development will be the keys to restoring rivers of sand.

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AQUATIC HABITAT MANAGEMENT CONCEPT - A STREAMSIDE MANAGEMENT STRATEGY FOR NATIONAL FORESTS IN ALASKA[1]

Dave R. Gibbons[2]

Abstract.--Located along the fisheries rich rim of the Gulf of Alaska, the Tongass and Chugach National Forests annually produce fishery resources that are vital to international trade for local and regional economies of the State. In 1985, estimates of the State-wide commercial salmon harvest exceeded 138 million fish, making it the largest recorded catch in State history. The habitats on National Forests contribute significantly to this commercial harvest and also to the recreational and subsistence harvest as well. To maintain this production, important freshwater habitats must be protected. The Aquatic Habitat Management Handbook was developed to provide the management direction to protect fish habitat. The handbook is an interdisciplinary, inter-agency document based upon fish habitat management concerns and the possibility of potential impacts. It incorporates the latest research findings pertinent to Alaska into specific management prescriptions. Additionally, a process for streamside management area width determinations is presented, along with a discussion of the goals and objectives of a recently initiated study on the interactions of fish and forest management in second-growth forests.

INTRODUCTION

Fishing and timber have been southeastern Alaska's most important industries for several decades. Since the 1950's when timber harvest increased dramatically to supply wood for a newly established pulp industry, the potential effects of timber harvest on Alaska's fisheries have become an ever-increasing concern.

In 1985, the State-wide commercial salmon harvest exceeded 138 million fish, making it the single largest recorded catch in State history. Additionally, for the last 7 consecutive years, the salmon harvest has exceeded 100 million fish. The habitats of the Tongass and Chugach National Forests contribute significantly to this commercial harvest and also to the recreational and subsistence harvest as well.

Because the best timber in a watershed is often found in valley bottoms in close proximity to streams, timber harvest and associated activities can reduce the productivity of fisheries habitat if they are not carefully planned and conducted. To maintain this productivity, these important freshwater habitats must be protected. This is not an easy task since the potential effects of timber management activities, including road building, on the habitats of salmonids vary from site to site, seasonally, and with the type of forest practice implemented. The spatial and temporal differences may be partially explained by climatic regimes, physiographic differences, and life cycles of the respective species.

For the last decade, the major controversy surrounding forestry/fishery interactions in the West has been the development of standards for the management of streamside vegetation. The central question is what quantity of merchantable timber must be left adjacent to fish streams to protect existing fish habitat quality and provide for suitable future habitat. Standards are highly variable and have ranged from 300 foot mandatory buffer strips to little or no vegetation along streams. The most logical of these is to leave a "proper mix" of deciduous and coniferous vegetation in sufficient quantities to protect fish habitat.

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[1] A paper presented at the 1987 National Convention Society of American Foresters held at Minneapolis, Minnesota on October 19-21, 1987.

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In this paper, I will highlight the Aquatic Habitat Management Unit (AHMU) concept in Alaska and its implications to fish and timber management and discuss the newly initiated second-growth vegetation management study on fish and their habitat.

When managing Aquatic Habitat Management Units, three aspects loom prominent: (1) AHMU width requirements; (2) specific prescription development for AHMU's; and (3) second-growth management along streams. A discussion of each of these will follow.

AHMU WIDTH DETERMINATIONS

The streamside "riparian" vegetation of southeast Alaska typically blends almost imperceptively into the upland forest zone. This seemingly subtle contrast is quite different from the riparian areas of the drier regions in the western United States. In those dry regions, water is frequently in limited supply and where it occurs in abundance, an obvious change occurs. In southeast Alaska, water is generally abundant in both terrestrial and riparian ecosystems. In the terrestrial ecosystem, excessive amounts of rainfall is a dominant factor affecting the type and productivity of plant communities. In the streamside "riparian" ecosystem, like those in the drier regions of the United States, water is somewhat more abundant than in the surrounding upland sites, with the exception of muskegs. How does one then classify this area?

In Alaska, the following criteria are used to guide the integration of soils, and channel type classification systems into the delineation of an Aquatic Habitat Management Unit.

Channel types (Marion et al. 1987) are used as the basis for grouping all the stream channels in a watershed into two broad groups: Incised and uncontained stream channels. Distinctly different geomorphic and hydrologic processes occur within these two groups. Incised stream channels are contained by the adjacent landform and have little effect on the adjacent landform. Mass transfer is predominantly in one direction: from landform to the channel. Mass transfer processes are mass erosion, leaf fall, and blowdown. The terrestrial ecosystem does directly influence the stream.

Uncontained (alluvial) channels are areas where a two-way interaction occurs between the adjacent landform and the channel. Mass transfer occurs through bank erosion, channel migration and overflow, leaf fall, and blowdown. Uncontained channel areas are important nutrient sources and processing zones, and generally contain a richer diversity of organisms than the incised channels. Flooding is a fundamental process in uncontained stream channels. Within these stream channels, the riparian area may be very broad and the adjacent terrestrial ecosystem may not directly influence the stream.

Uncontained stream riparian areas occur predominately within floodplain, alluvial fan, and dissected footslope landforms. These areas occur mostly along lower valley areas. These riparian areas are extremely dynamic as can be seen by the type of soils and plant communities occurring within these areas.

In uncontained channels, the outer boundary for the AHMU coincides with the outer boundary of associated landform. In some cases in southeast Alaska, these boundary distances have been as wide as 600 feet. In contrast, incised riparian areas occur predominately along the upper valley and mountain slope positions. These riparian areas, as the name implies, have stream flows which are well contained within the channel cross-sectional area. Channel banks are steep and generally composed of large material, either consolidated bedrock or well packed boulders, rubble, and cobbles. The riparian vegetation along these streams is often a narrow strip. The width of the riparian areas along these channels are determined by the identification of the adjacent unstable terrestrial soils that may directly influence the stream. These generally disjoined units are connected into a manageable AHMU by prescribing a 100 foot-wide riparian area as defined in the National Forest Management Act and Forest Service policy. This classification provides the land manager with an inventory description and map of of riparian areas.

AQUATIC HABITAT MANAGEMENT PRESCRIPTIONS

Once the unit is defined, prescriptions for management are needed. Management schemes to maintain structurally and functionally diverse streamside management areas have been difficult to develop because of conflicting resource demands and the shortage of information on effects of silvicultural treatments on the biological and physical dynamics of streams. Thus in the past, management has generally relied on the vacuous use of prescriptions (i.e. mandatory buffer strips) that result in inefficiencies and inequalities as they do not provide for the necessary flexibility to balance the management between timber and fish. The Aquatic Habitat Management Handbook (1986) further refines the management. First it defines three classes of habitat. Classes are determined according to the importance of the habitat to fish. These classes are defined as:

1. Class I AHMU. Streams with anadromous fish habitat or adfluvial resident sport fisheries. Also included is the habitat upstream from migration barriers known to be reasonable enhancement opportunities. Stream gradient is generally less than 6%.

2. Class II AHMU. Streams with resident fish populations and 6-15% gradient (can also include streams from 0-6% gradient where no anadromous fish occur). These populations have limited sport fisheries value. They generally occur upstream of migration barriers or steep gradient streams and other habitat features that preclude anadromous fish use.

3. Class III AHMU. Streams with no fish present but have potential water quality influence on downstream fish habitat. Stream gradient is usually in excess of 15% but may contain lower gradients.

The handbook provides guidance in facilitating fish habitat management through prescriptions while addressing multiple-use objectives. While it ensures a consistent approach throughout the National Forests in Alaska, it allows latitude for site specific prescriptions in response to habitat differences.

Salmonid habitat is complex but can be partially described using measurable physical elements. Maintenance of fish production relies on key habitat parameters such as proper water temperature, large woody debris and substrate composition. A precise blend of these key parameters creates good fish habitat.

When these key habitat parameters are compared to the potential impacts from land management activities, seven general fish habitat management concerns can be identified. These include: (1) streambank and streambed stability; (2) increased and/or depressed stream temperature; (3) fish passage through culverts; (4) special road construction techniques; (5) maintenance of existing water quality; (6) large woody debris; and (7) stream productivity. These concerns are the link between the AHMU concept and the specific fish habitat management objectives and prescriptions. These concerns are listed in Table 1 and are related to AHMU class applicability.

The management guidance provided in the handbook is organized within three levels. Class I AHMU'S require a range of timber harvest options from no cutting to complete harvest of commercial volumes of timber along streams. They contain the most restrictive timber harvesting prescription.

While class II and III objectives are respectively less restrictive. Specific prescriptions to meet these objectives were developed by an interdisciplinary team (IDT) using the best available data specific to southeast Alaska. In a recently completed 5-year plan, it was estimated that 80% of the timber within 100 feet of the stream in class I, 40% in class II, and 10% in class III streams should be maintained to meet the objectives for maintenance of fish habitat.

A detailed discussion of one of the seven concerns, large woody debris (LWD), will provide an example of the knowledge and level of detail provided by the handbook. In addition to the section in the handbook on LWD, the Alaska Region of the Forest Service has additionally published an interagency brochure entitled: "Fish in the Forest - Large woody debris in streams, a new management approach to fish habitat" by Gibbons et al. 1986.

Table 1.--Frequency that fish habitat management concerns will result in prescriptions affecting land management activities.

Management Concern	FMHU Classes		
	Class I	Class II	Class III
1. Maintenance of stream-bank and stream channel stability	1	1	1
2. Maintenance and/or enhancement of optimum stream temperature	1	1	2
3. Fish passage through stream crossing structures	1	2	3
4. Maintenance of water quality within established State standards	1	1	1
5. Maintenance of existing and providing future sources of large woody debris (LWD)	1	2	3
6. Maintenance or improvement of primary and secondary biological productivity within or adjacent to streams (including Second-Growth management).	1	3	3
7. Timing of bridge and culvert construction	2	3	3

1 - Always 2 - Occasionally 3 - Never

LARGE WOODY DEBRIS

All western Regions (1, 5, 6, and 10) of the USDA Forest Service have some specific standards for leaving large trees in streamside areas for fish habitat considerations. Forests in Oregon and Washington (Region 6) specify 9 to 25 trees greater than 16 inches dbh per acre for many anadromous fish streams. Forest guidelines in Region 6 often specify that 60 to 90% of the AHMU should be in mature or old-growth timber (Sedell et al., In press).

The AHMU Handbook in Alaska has a set of standards and guidelines based upon a sample from a large number of natural sites. The mean number of stems greater than 12 inches dbh per 100 feet of stream is between 13 and 24 for undisturbed habitat conditions. The guidelines require minimum tree sizes for specific stream widths: 1 to 20-foot wide stream require at least 12-inch dbh trees; 21 to 50-foot width requires 20-inch dbh trees; greater than 50-foot width requires 30-inch dbh trees and preferably with root wads attached. The minimum tree length for all channel widths is equal to 1.5 times the channel width.

Smolt yield increases are also predicted if woody debris is added to aquatic systems (fig. 1).

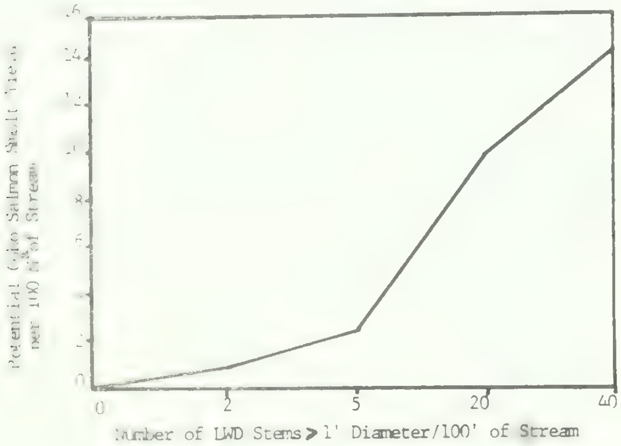

Figure 1.--Predicted coho salmon (Oncorhynchus kisutch) smolt yield as related to woody debris in streams of southeast Alaska.

These are preliminary data for Alaska and can not yet be reasonably extrapolated to other geographic areas. However, it does illustrate how such debris loading is related to potential coho salmon smolt yield. In that over 85% of the anadromous fish bearing streams in Pacific Northwest and probably elsewhere, have been cleaned of large woody debris, have no large conifers left in the streamside areas or have been scoured by debris torrents, knowledge of such relationships is useful for future planning and rehabilitation (Sedell et al., In Press).

SECOND-GROWTH STUDY

The interactions of fish and forest management in second-growth vegetation in Alaska are not completely understood and with the increasing portions of the Forests being converted to second-growth status, more knowledge is needed. The premise for a study initiated in 1987 is that fish habitats in second-growth forests are qualitatively different from habitats in old-growth, and must be managed to ensure that fish production can be maintained at least at pre-disturbance levels. The anticipated life of the project is 5 years.

Timber harvest in the riparian zone imposes both long- and short-term changes in stream channel. The former best management practice of harvesting to the streams edge and subsequently removing woody debris from stream channels, for example, has resulted in a large number of stream channels in second-growth condition that lack the structure provided by large, stable woody debris and the necessary light production for good utotrophic stream production. Fish production in these streams has been lowered and is not expected to recover until the surrounding forest can provide new inputs of debris and light.

Resource managers can influence the type and quality of aquatic habitat in second-growth forests by manipulating carefully selected features. To accomplish habitat rehabilitation or improvement objectives in a biologically meaningful and efficient manner requires knowledge of the basic factors that determine the suitability of freshwater habitat for juvenile salmonids: food, living space, cover, and water quality.

The objectives of the study are:

1. Develop and document information on the production capability of aquatic habitats in second-growth forests.

2. Identify factors and processes influencing the production of juvenile anadromous salmonids in streams of second-growth forests.

3. Initiate experimental manipulations of stream channels, riparian vegetation, and fish populations to enhance growth and survival of juvenile anadromous salmonids.

4. Recommend alternative management programs, when necessary, for streams located in second-growth forests.

The management applications and long-term goals of the study will be to: (1) document information on the productive capacity of anadromous fish habitat in second-growth forests;

(2) identify factors that limit the production of anadromous fish; (3) predict the effects of silvicultural practices in second-growth forests on aquatic habitats; and (4) develop methods and procedures to maintain high levels of fish production in second-growth forest streams.

DISCUSSION

Today in southeast Alaska, resource managers are confronted with the responsibilities of making many significant decisions relating to the future use of Alaska's renewable natural resources. In the past 10 years, increased public attention has focused on critical environmental issues affecting the use of many natural resources, including timber and fish. Timber and fish are the two of the three most important resources with the greatest present economic value in southeast Alaska, and since, in many instances, each watershed produces both resources, it is inevitable that conflicts will arise when resource decisions are made in favor of one resource over the other. These potential conflicts which can arise from unaltered maintenance of streamside vegetation, improper culvert construction and other management actions will continue to occur as demands increase for a variety of goods and services produced from a static or declining land base. It is not a question of fish or timber since both resources are highly used, but rather integration of management and effective use of existing guidelines. As Martin (1976) points out, timber harvesting/fisheries issues are not simple to answer, but can only be resolved through proper application of existing knowledge, and for the most part, by the application of existing laws, regulations, and management guidelines. Recent legislative activities, special interest group pressures, judicial rulings, standards and prescriptions promulgated by private conservation groups, state and federal land management agencies provide ample evidence that the resolution of the timber/fisheries conflicts is one of our current pressing problems.

It is clear that one of the major problems concerning timber and fisheries management involves the management itself: namely, the effective application of existing guidelines. Many past management guidelines have been developed for southeast Alaska as a result of studies on the effects of timber harvesting on fish, water and soil throughout the Pacific Northwest. The new tiered prescriptions described are based upon recent research in southeast Alaska and provide the impetus and direction toward providing greater protection. The second-growth management study is aimed at providing answers pertinent to stream habitat manipulations related to past management priorities. The Aquatic Habitat Management concept, provides a viable system, which can be used to both manage timber and fisheries production in Alaska.

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MANAGEMENT OF RIPARIAN ZONES AND STREAM CHANNELS TO BENEFIT FISHERIES[1]

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Abstract: Riparian zones and stream channels can be deliberately modified directly or indirectly to increase fish populations that support sport fisheries. This paper focuses on field-tested techniques that have been used to successfully restore damaged riparian zones and stream channels or enhance naturally low fish carrying capacities of undamaged streams.

Twenty-two case history evaluations are reviewed (primarily representative of low and moderate gradient trout streams in Wisconsin) that documented quantitative improvements in salmonid populations and angling recreation as a result of management efforts to modify riparian zone vegetation and/or stream channel morphometry.

Twelve ecological principles of restoring or enhancing fish carrying capacity of streams are also reviewed.

INTRODUCTION

Pristine, unaltered riparian zones along streams of third order or higher classification are the rare exception rather than the norm within the borders of the 48 contiguous states. Direct or indirect consequences of agricultural, silvicultural or urbanization activities have deleteriously impacted both the greenbelt terrestrial zones and stream channels of nearly all such habitats (CEQ 1978).

It is not my intent in this brief review to characterize the diverse impacts of such ubiquitous degradation or to attempt a synthesis of the growing multiplicity of governmental and private agency policies and programs aimed at restoring the biotic integrity of riparian and instream habitats. Certainly much money and effort have been expended since the turn of the century to reverse degradation of riparian areas (Brouha 1987), and professional conferences, such as this one, should help to focus even greater effort on restoration activities. Much challenging work remains to be done: (1) to resolve conflicts over best societal use of riparian zones and the streams they border, (2) to prioritize sites most in need of remedial action, (3) to increase financial support to carry out rehabilitation efforts, and (4) to see to it that state-of-the-science management techniques are implemented once decisions have been made to proceed with restoration or enhancement programs.

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[1] A paper presented at the Convention of the Society of American Foresters held in Minneapolis, MN, 18-21 October 1987 as part of Working Group C5 - Wildlife and Ecology.

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This paper focuses on one category of such state-of-the-science management procedures - techniques used to restore and enhance fish habitat. These techniques have received their greatest innovation, application and evaluation within programs aimed at improving instream and near-stream environmental conditions to benefit various species of salmonids (trout and salmon) during periods of stream-residency.

Considerable success has been achieved during the past three decades to attain this objective via a variety of techniques applicable to a variety of environmental conditions. I will describe some of these useful techniques and cite case history examples of successful applications.

Although the techniques and examples to be mentioned are all drawn from the narrow field of management focused on salmonid habitats, many of these techniques should be transferrable to riparian zones and streams that support other game fish species too.

Greatest application of salmonid habitat improvement projects, and successful outcomes, have centered in and along upper midwest streams of low to moderate gradient (0.5 to 1.5%) and where annual streamflow is largely dependent on groundwater input rather than surface runoff. As Platts and Rinne (1985), Hall and Baker (1982), Parkinson and Slaney (1975) and other investigators have cautioned, some of these midwestern-developed techniques are not automatically transferrable to streams and riparian zones in more arid regions or where stream gradients are more steep. I wholeheartedly agree with such precautionary advice to be aware of the limitations within which each habitat improvement technique is applicable, but I also stress the urgent need to more vigorously apply successful field-tested techniques to the many thousands of miles of degraded riparian corridors and stream channels where transferrable technology is "on the shelf" and ready for use.

RESULTS AND DISCUSSION

Examples of 22 biologically successful salmonid habitat improvement projects are summarized in Table 1 in roughly descending order from the most simple techniques to the more complex. Sixteen of the case history sites are located in Wisconsin, plus one each from British Columbia, Colorado, Minnesota, Montana, Pennsylvania and South Dakota. Techniques varied from such simple procedures as streambank fencing (Sheep Creek, CO) to prevent streambank and riparian zone damage by cattle, placement of large boulders in a stream channel to provide midstream cover for young salmon (Keogh River, B.C.), or adding half-logs to provide cover for adult trout (W. Br. White River, WI) to much more intensive modification of stream channel morphometry via installation of bank covers and current deflectors (Big Roche-a-Cri Creek, WI and Lawrence Creek, WI).

Trout carrying capacity of some streams in Wisconsin was also enhanced by modifying the kind of terrestrial vegetation along the streambanks - cutting down dense stands of brush and trees so that a strong turf of natural grasses could become established. Reduction in shade canopy also allowed more sunlight energy to enter such streams and stimulate greater abundance of rooted aquatic plants (Lunch Creek and Spring Creek).

On other small heavily shaded streams, cut brush was put to benefical use by tying it in bundles that were anchored along the shallow sides of stream channels and along the inside banks. Such "brush bundles" provided short-term cover for small trout and acted as sediment traps and current deflectors that helped to gradually create narrow and deepen stream channels (Beaver Brook and Radley Creek).

Some of the rehabilitation projects involved use of several techniques to achieve synergistic benefits: Blockhouse Creek, PA; Dogtown Creek, WI; Rapid Creek, SD; Split Rock Creek, MN.

Regardless of the choice of procedures employed to restore and enhance salmonid habitat, projects that have proven to be successful are consistently due to adherance to several biological principles. There are at least 12 such "principles" that I recommend for consideration when devising an administrative policy/philosophy base for a program of salmonid habitat management and as on-site guidelines to keep in mind when implementation plans are developed and implemented.

SOME GUIDING PRINCIPLES FOR SALMONID HABITAT MANAGEMENT[1]

1. Learn from nature. What biotic and abiotic factors make locally good streams good? Try to restore the health of degraded streams based on local observations of healthy streams.

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[1] Most of these principles have been reworded in part or borrowed intact from papers authored by White and Brynildson (1967) and White (1978). See Literature Cited for completed references.

Table 1. Summary results of 22 successful salmonid habitat improvement evaluations.

Improvement Technique	Principal Investigator	Application Site	Postimprovement Biological Changes
streambank fencing	R. Stuber (1985)	Sheep Creek, CO	Biomass of trout (mainly brown trout) was 96% greater in 1983 and 127% greater in 1984 in fenced study zones than in unfenced zones.
	D. Gunderson (1968)	Rock Creek, MT	Average number of brown trout over 6 inches was 27% greater and average biomass was 44% greater in ungrazed reach than in adjacent grazed reach.
boulder groupings	B. Ward and P. Slaney (1980)	Keogh River, BC	200% increase in coho salmon smolts (to 4800/mile).
streambank riprap	R. Kerr (1985)[1]	Willow Creek, WI	Average number of brown trout over 6 inches increased by 35% and average number over 10 inches increased by 86%.
half-logs	R. Hunt (1978)	W. Br. White River, WI	Average number of brown trout over 10 inches in April increased by 553% and average biomass increased by 187%.
	B. Apelgren and S. Stewart (1984)[1]	Kinnickinnic River, WI	In 5 study zones the average number of brown trout over 6 inches increased by 41%, the average number over 10 inches increased by 34% and average biomass increased by 51%.
streambank debrushing	R. Hunt (1979)	Spring Creek, WI	Average number of brook trout over 6 inches in October increased by 53% and average biomass increased by 54%. Growth ratio of ages 0-II also improved.
	R. Hunt (1985)	Lunch Creek, WI	Average number of brown trout over 6 inches in September increased by 51% and average number over 10 inches increased by 82%.
streambank debrushing and half-logs	R. Cornelius (1984)[1]	Clam River, WI	Average midsummer abundance of brook trout and brown trout over 6 inches increased by 65% and 525% respectively.
streambanks debrushing, brush bundles and half-logs	R. Hunt (1986)	Radley Creek, WI	Average number of brown trout over 10 inches increased by 41% in one study zone and by 42% in another study zone. Average biomass increased in the two zones by 35% and 50%.
bank covers and current deflectors	R. Hunt (1976)	Lawrence Creek, WI	Average number of brook trout over 8 inches increased by 192% and average biomass increased by 130%. Angler hours increased by 196% and harvest increased by 191%.
	R. White (1972) and WDNR (1975)[1]	Big Roche-a-Cri Creek, WI	Average biomass of brook trout increased initially by 159% and long-term by 859%. Angler harvest increased initially by 96%. (No long-term measurement made of angler harvest.)
	T. Thuemler (1978)[1]	MacIntire Creek, WI	Average number of brook trout and brown trout over 6 inches in midsummer increased by 84% and 431% respectively. Average biomass of brook trout increased by 40% and that of brown trout increased by 490%.
"skyhook" bank cover and current deflectors	A. Hauber (1978)[1]	Plover River, WI	Average number of brook trout and brown trout over 8 inches in midsummer increased by 128% and 200% respectively. Average number of brown trout over 14 inches increased by 253% (to 67/mile).
	A. Hauber (1985)[1]	Prairie River, WI	Average number of brook trout and brown trout over 6 inches in midsummer decreased by 40% and increased by 426% respectively. Average biomass of brook trout decreased by 41% but average biomass of brown trout increased by 578%.
	A. Hauber (1985)[1]	Hunting River, WI	Number of brook trout and brown trout over 6 inches in June increased by 26% and 91% respectively. Biomass of brook trout and brown trout increased by 20% and 88% respectively.
sandbag bank cover and current deflectors	S. Ironside (1984)[1]	Neenah Creek, WI	Average number of brown trout over 6 inches in midsummer increased by 151% in Sta. 1 and by 756% in Sta. 2. The average number over 10 inches increased by 75% in Sta. 1 and by 124% in Sta. 2.
bank covers, current deflectors riprap	R. Glover (1986)	Rapid Creek, SD	During the 3rd-5th post development years average abundance of brown trout increased by 357% while average abundance of Mt. suckers decreased by 89% and average number of white suckers decreased by 70%.
	S. Johames (1985)[1]	Dogtown Creek, WI	Average number of brook trout over 6 inches in September increased by 105% and average biomass increased by 65%.
jack-dams, tip deflectors	D. Spotts (1986)	Blockhouse Creek, PA	Average biomass of brown trout in late summer during the 3rd and 4th post development years was 752% greater than predevelopment biomass.
streambank debrushing, brush bundles, bank cover and riprap	S. Johannes (1985)[1]	Beaver Brook, WI	Average number of brook trout and brown trout over 6 inches in July increased by 65% and 125% respectively.
current deflectors, bank covers and log/rock dams	J. Hale (1969)	Split Rock Creek, MN	Average number of brook trout in September increased by 356% and average biomass increased by 68%. Average biomass of white suckers decreased by 81%. Angler hours increased by 203% and harvest increased by 362%.

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[1] Personal communication memoranda from principal investigators to R.L. Hunt (see In Press Literature Citation).

2. Focus on identifying "limiting factors" at work in each candidate stream for renovation. Try to eliminate or ameliorate those factors that depress salmonid carrying capacity.

3. Maintain or enhance baseflow whenever possible (natural flow of a stream when it is not being augmented by surface runoff). Riparian zone and entire watershed management activities should be considered to achieve greater and more stable baseflow.

4. Consider species-specific and age-specific requirements of the salmonids present, including both environmental suitability and social interactions with other fish species and/or age groups.

5. Follow a logical sequence of habitat improvement steps. These steps should usually include:
Examination of Site
Diagnosis of needs
Prescription of remedies
Planning and organization of work to be done
On-site treatment/development
Evaluation of results
Maintenance of development

6. Disguise artificiality of man-made structures or modifications of channel shape. Restore esthetic conditions as quickly as is practical.

7. Tailor management activities to the individual stream. Do not use techniques just because they have "worked" elsewhere, unless personalities of the streams are similar.

8. Preserve, restore and accentuate the two most common natural characteristics of streams - the meandered channel profile and the riffle/pool sequence.

9. Work with, not against, the inherent capacity of streams and watersheds to repair their biotic health.

10. Encourage the right kinds of streambank vegetation to become dominant, depending on the character of the stream and riparian zone.

11. Make the streamflow work beneficially. Bring the main threads of flow close to hiding/resting/security cover for trout.

12. Integrate habitat management in the stream channel with other terrestrial management activities along the stream's riparian zone and the larger watershed (see also No. 3 above).

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ECONOMIC CONCEPTS RELATED TO THE COMPARISON OF RELATIVE VALUES OF TIMBER AND FISHERY RESOURCES[1]

David B. Rockland[2]

Abstract.--This paper addresses the economic benefit concepts that are relevant to comparing the relative values of timber and fishery resources. Each concept requires consideration in decisions affecting resource management of conflicting resource users. The concepts of economic value and economic impact are differentiated. Within the category of economic value, user values and non-user values are explained. Several of the methods by which economic benefits are quantified are presented. Standard value concepts for timber production and sport fisheries are compared with emphasis on how a manager should make tradeoffs between the two resource user groups. Means by which to make "apples to apples" comparisons are provided.

INTRODUCTION

The purpose of this presentation is to discuss the key economic concepts pertaining to sport fishing and their relevance to management decisions. Two years ago I had the pleasure of taking a unique job -- an economic advocate for sport fishing. During this period, I have seen how important economics currently is, and how important it can be, to the management of natural resources. Managers are asking economic questions in their decision-making process.

However, sport fishing economics is a term that some people have difficulty with. The terms sport fishing and economics are felt not to go together. Sport fishing is just fun, or frivolous and has no economic value or worth. The major point of this presentation is that sport fishing and fishery resources are of tremendous economic significance. Those economic benefits must be considered in the management of forestry resources.

WHY ECONOMICS?

The forest manager is faced with two confounding problems:

1) He/she has a budget to invest in the resources he/she manages. How does he/she invest that budget to create the greatest returns for the public for whom he/she is a steward of the resource?

2) Certain timber harvest strategies may impact fish and wildlife resources. How does the manager decide if the benefits associated with the timber harvest outweigh the costs imposed on the fish and wildlife resources?

Economics can provide the manager with a basis by which to address these questions. Any student in an economics course hears the same thing the first day of class: "What is economics?" The general answer is that economics is the study of the allocation of scarce resources amongst competing unlimited wants. Managers can use economics as a tool to help them make a decision concerning the resources they manage.

There are two general economic questions relevant to the managers: allocation of natural resources and allocation of financial resources, or investment. The resources the managers can use economic information for managing are fish and timber and money.

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The allocation of natural resources is a prevalent issue in decisions regarding which user group can use a resource. For example, if timber harvesting ruins fish habitat, the manager needs to decide who gets to use the resource, the timber harvestors of users or the fishery resource such as sport and commercial fishermen. Do the benefits from fishing exceed the foregone benefits in timber harvesting if the forest products industry were restricted or vice versa?

The allocation of financial resources is a question of how to spend one's budget. For example, should I stock this stream or plant and cultivate trees? Should water quality tests and stream enhancement be the focus of my staff's efforts or managing and enhancing timber products? The manager's decision need not always be an either/or, but may focus on enhancing all uses of natural resources simultaneously.

The economic benefits associated with fishery resources are probably unfamiliar to this audience of forestors. Therefore, the following discussion describes the economic benefits of fishery resources. Most of the discussion focuses on sport fishing, but the concepts are clearly relevant to other resource uses.

ECONOMIC BENEFITS: DEFINITIONS

There are two basic benefits that result from the fishery resource -- economic impact and economic value. An economic impact is the answer to the question: "What is the economic activity generated by the use of the resource?" Economic value is the answer to the question: "How much value do people place on the resource?" While these two benefits are distinct, they are not entirely inseparable. Neither benefit type has greater merit as an economic concept than the other. Rather, they answer two distinct questions.

Each question is important for different reasons. Local and state government officials often base decisions on the economic impact in their region which translates into jobs, income, and tax receipts. In contrast, economic value is the value people place on the fishery resource. This concept is certainly important to those people who value the sport fishing experience.

Values

Values attributable to the fishery resource occur to both users and non-users of the resource. User values take three forms: consumptive use, non-consumptive use, and indirect use. Consumptive use values accrue to commercial and sport fishermen and consumers of the fishery resource. "Catch-and-release" fishing is considered a consumptive use because the actual activity the user undertakes is most similar to "catch-and-keep" fishing. The fact that sport fishermen go fishing in preference of another activity and consequently spend money, time, and effort doing so, indicates they value the opportunity to go sport fishing and value the fish stock.

Just as fishermen place a value on fish and fishing, so do non-consumptive users such as photographers, snorkelers, aquarium visitors, and others who receive value from directly viewing but not consuming the resource. While non-consumptive user values may have greater application to wildlife (i.e. birdwatching), it is also clearly relevant to fisheries. The popularity of non-consumptive snorkeling and scuba-diving attests to the validity of the concept of non-consumptive use value as does the prevalence of people who watch salmon on their annual spawning run. A willingness to pay before foregoing the activity is an indication of a value of the fishery resource to non-consumptive users as are the expenditures, time, and effort made to undertake the activity.

An indirect use is when people do not come into contact with the resource, but still derive personal satisfaction from it. Indirect use for a fishery resource includes reading about fish, viewing pictures of fish, watching television specials about fish, and related activities. Examples of indirect use are people who enjoy paintings of a trout rising to fly or a commercial fishermen setting his nets. People spend money (e.g. books, magazines, television) to use the resource directly which in itself is an expression of value. There may be additional monies that an indirect user would be willing to pay before having to forego the opportunity for indirect use.

Non-users of the resource also may place a value on the fish. These values are also referred to as intrinsic values and result from sentiments about the resource that are not current-use related. Non-use values are categorized as option and existence values. Option value reflects uncertainty about future resource use and represents the value the individual places on the availability of resource use in the future. In other words, individuals will value the option of having the resource available in the future in the event they want to use it.

The value of the option of future use is termed "ordinary option value." Quasi-option value is where new information is expected in the future and therefore a value exists for postponing a decision about use until that information exists. For example, if there might someday be research in the future might produce a product from a species of wild trout that cures leukemia, there is a quasi-option value of holding off the irreversible loss of that strain of trout until more research is undertaken.

Some people may value a fishery resource even if they know they will never use it themselves. These values are called existence values. Existence values generally are motivated by altruism or the unselfish concern for other people or the fishery resource.

One type of existence value is bequest value which captures the desire to endow the resource to future generations. This is the value placed on knowing one's kids will be able to go fishing or eat salmon. If you are willing to have some of your tax dollars go toward stocking programs, where the fish would only be available for your children, then you have a bequest value associated with that stocking program. Other existence values may be motivated by altruism toward the fishery resource itself in the same way people place a value on knowing that whales and bald eagles exist in the wild and are not extinct.

Impacts

The purchases made in the course of consumptive, non-consumptive, or indirect use may impact the local, state, and/or national economies. These impacts are expressed in terms of jobs, sales, or wages and salaries. Total economic impact is based on expenditures made by consumptive, non-consumptive, and indirect users. The fact that total economic impact exceeds the expenditures results from the premise that sales in one industry not only impact that industry but the industries that supply goods and services to the initially affected industry.

Three levels of economic impact are discernable for sport fishing:

- o Direct Impact: The initial purchases by the recreational fishermen.
- o Indirect Impact: The purchases of inputs by the directly impacted business to produce the goods and services demanded by recreational fishermen. The initial round of indirect purchases has further indirect impacts as the suppliers to the direct businesses make purchases to meet that demand.
- o Induced Impact: The purchases of goods and services resulting from the wages paid by the directly and indirectly affected businesses. Induced impacts have additional indirect and induced impacts as well.

An example of the direct, indirect, and individual impacts would be where the direct impact was the purchase of a fishing rod by an angler. The indirect impacts would include the purchase of graphite, paint, and guides to make the rod. Further, indirect impacts might include the purchase of pigments by the paint supplier and aluminum by the guide supplier. The induced impact would include the purchases by households with wages made by employees of the tackle, graphite, paint, guides, pigment, and aluminum manufacturers.

Economic impact is a very important concept to fisheries managers. Economic impact measures the activity in the region's economy associated with the use of the resource which is very important to the economic vitality of the region. However, economic impact cannot be considered a "true" benefit of the fishery resource because economic impact results from the costs users incur to use the resource. A problem with considering these costs as benefits is that the greater the cost, the greater the benefits. A "true" economic benefit is the value of a good or service less all the costs of creating that product. Therefore, economic impact is not a "true" economic benefit because it results from the costs of creating the product (i.e. a fishing trip). However, economic impact is the measure of the benefit that industry and wage earners receive from the use of the fishery resource. Fishery management decisions should be considered in terms of industry impact as well as user and non-user values because industry impact translates into jobs, income, and sales.

A key point in understanding value and impacts is that they are not all additive. One does not add the direct, indirect, and induced impacts to the various types of user and non-user values to derive total benefits. Rather, the sum of the direct, indirect, and induced impacts is the total economic activity associated with the fishery and responds to the questions: "How is the economy affected?" or "How many jobs are affected?" Consumptive user value is how much the resource consumers (i.e. sport fishermen, commercial fishermen, fish consumers) value the opportunity to use the resource. The other values reflect amounts non-users value the resource either in terms of an option to someday use it, for their offspring to use it, or for other reasons.

ECONOMIC BENEFITS OF FORESTRY

Forestry produces economic benefits that follow the same general concepts as fisheries. Forests produce values to users such as timber production. Timber has value to both consumers of the resource, such as a homeowner whose house is made of wood, and producers of wood products who use trees as an input to their production.

Forests also produce values to non-consumptive users. For example, people value walks in the woods that do not involve consumption of the resource. Indirect users value the opportunity to view forests such as in magazines and on television.

Non-users of the forest also place a value on it. People may value the option to someday walk in the forest or have a home built of wood. Furthermore, society places a value on the existence of a forest even though they may never touch, see, or otherwise experience the forest or its products.

Timber production also creates economic impacts. These are the economic benefits with which this audience is most likely to be familiar. Jobs are created in a range of industry including harvesting, wood product manufacturing, wholesale and retail. These economic impacts may also be expressed as sales, tax revenues, wages and salaries, or output.

WHAT ORDER OF MAGNITUDE ARE THE ECONOMIC BENEFITS OF SPORT FISHING?

The sport fishing industry is comprised of businesses that supply goods and services to sport fishermen. It includes hotels, motels, restaurants, tackle manufacturers, boat manufacturers, magazine publishers, and gasoline distributorships. The U.S. industry was worth about $28.2 billion at retail in 1985. In other words, on the order of $28.2 billion was spent by sport fishermen for sport fishing in the form of direct impact. If the indirect and induced impacts are added, the total economic impact on the national economy of sport fishing is between $50 billion and $75 billion. Expressing those same numbers in terms of employment, on the order of 800,000 jobs exist in the United States as a result of sport fishing.

It should appear phenomenal how much economic activity occurs due to sport fishing. However, it is the number two form of recreation among adult Americans. More adults went fishing than played basketball, football, or tennis, or went bicycling. It is the top activity among adult men, fifth among women.

The value placed on sport fishing by sport fishermen is also of tremendous magnitude. For freshwater fishing, the total value in excess of expenditures has been estimated to be between $23.8 billion and $54.1 billion, with an average of $38.9 billion. In other words, in addition to the amount freshwater fishermen spent to go fishing in 1985, they valued the opportunity to do so by an additional $38.9 billion. Of this amount, approximately 28 percent was attributed to trout fishing, 60 percent was attributed to bass fishing, and the remaining 12 percent was attributed to rough fishing.

Since we are in the State of Minnesota, summary economic statistics of the economic impact of sport fishing for the State may be of interest. Those are:

1) The total retail sales associated with sport fishing in Minnesota in 1980 was $468,845,000 according to the U.S. Bureau of the Census. In 1985, the estimated retail sales were $681,875,195. The 1985 total can be disaggregated by type of merchandise as follows:

   o Food and Lodging -- $141.8 million;

   o Transportation -- $108.4 million;

   o Licenses -- $24.7 million;

   o Boating and Fishing Equipment -- $323.5 million; and

   o Other -- $83.5 million.

2) These retail expenditures have further economic effects on the State of Minnesota, estimated to be $1,287,266,000 in total output and $303,484,000 in total wages and salaries.

3) The total employment associated with sport fishing in Minnesota is approximately 15,700 person-years. This corresponds to roughly 18,000 to 20,000 people who are employed as a result of sport fishing.

APPLES TO APPLES COMPARISONS

As demands on natural resources and public funds increase, managers increasingly have to choose between competing interests. In those circumstances, managers can use commensurate economic estimates to make tradeoffs between mutually exclusive resource uses or investment of public revenues. As seen here by the magnitude of the economic benefits associated with sport fishing, managers need to be cognizant of the possible effects of their decisions on the sport fishing industry and the values placed on fishery resources.

The temptation often exists to choose an economic benefit measure such as economic impact (jobs) in the state and then see whether timber production or sport fishing has the bigger number. For example, suppose sport fishing creates 100 jobs, and timber production 10, the temptation is to argue that because sport fishing creates ten times more jobs than timber, timber production should be eliminated to avoid possible negative impacts on fish habitat and fish resources.

By allocating the resource away from timber production, 10 jobs are lost in timber, and the total jobs (fishery plus timber) from the resource declines from 110 to 100. For the allocation to sport fishing to make economic sense, there must be a gain in total jobs to an amount greater than 110; there must be an increase in employment in the sport fishing industry that exceeds the 10 lost jobs in the timber industry.

In sum, simply comparing the magnitude of relative total economic benefits does not provide a good case for allocation. Rather, the total benefits from the entire resource are determined and the question is then asked, "Is there some way to redistribute the fish resource such that the total pie of benefits from the resource grows?" There are, however, cases where it is not possible to determine tradeoffs between both user groups and relative comparisons between user groups are the best that can be done.

When making comparisons or tradeoffs between forestry and sport fisheries, the following comparisons are relevant:

a) Retail value of timber products vs. retail expenditures by sport fishermen.

b) Total economic impact of timber production and distribution vs. total economic impact of expenditures by sport fishermen.

c) Profit earned by businesses in timber production and distribution vs. profits earned in the businesses distributing and producing goods and services purchased by sport fishermen to go fishing.

d) The values consumers place on the opportunity to purchase timber products to the value people place on the opportunity to sport fish.

These are certainly not all the "apples to apples" comparisons that can be made. However, they do provide the guideline that likes must be compared to likes. Furthermore, tradeoffs and comparisons can be made between sport fishing, and fisheries values in general, and those associated with timber production.

CONCLUSION

Economics offers a system of measures to allow managers to make allocation decisions between alternative uses of natural and financial resources. Using economics, the manager can gauge, in part, if he/she is getting the greatest "bang for the buck" in terms of investment of money or allocation of natural resources.

Fishery resources have tremendous value. A major source of these values is sport fishing which employs 800,000 people nationally and has a user value of approximately $40 billion for freshwater fishing alone. Where fishery resources are potentially degraded by forest management and harvest practices, managers must make tradeoffs between these two activities. Failure to take account of all the relevant economic measures can be disasterous, resulting in unemployment and losses of important values to our society and future generations.

FINDING OUT AND TELLING

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it--in short, "finding out and telling." As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

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Guide to Analyzing Investment Options Using TWIGS

Charles R. Blinn, Dietmar W. Rose and Monique L. Belli

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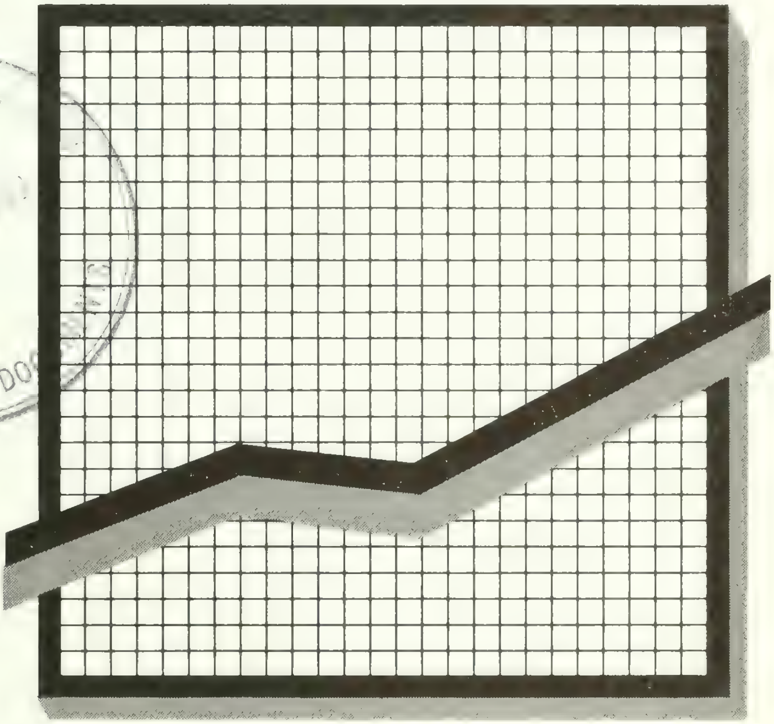

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PREFACE

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GUIDE TO ANALYZING INVESTMENT OPTIONS USING TWIGS

Charles R. Blinn, Dietmar W. Rose, and Monique L. Belli

Forest landowners and managers face a myriad of possibilities when evaluating investment opportunities and potential timber management prescriptions. The various management alternatives need to be identified and evaluated to determine how funds should best be allocated to meet the landowner's or land manager's objectives.

The TWIGS microcomputer program (Belcher 1982, Miner *et al* 1988) can help managers estimate changes in both timber and financial resources under different management prescriptions. TWIGS, a model that projects the growth and death of individual trees in the context of a stand, is a tool that allows forest managers and planners to interactively "manage" and "grow" existing stands with a computer.

The economic analysis of TWIGS version 3.0 summarizes annual cash flows, calculates several measures of economic performance on a before-tax basis, and evaluates the economic uncertainty associated with a management alternative. With this information, forest managers are better able to analyze timber management investment alternatives.

This paper briefly introduces investment analysis concepts and discusses how an analysis might be performed with both the Central and Lake States variants (version 3.0) of TWIGS, expanding on the example found in Miner *et al.* (1988). A separate report describes investment analysis in greater detail (Rose *et al.* 1988).

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BACKGROUND INFORMATION

The components that should be part of any investment analysis include: (1) developing a clear statement of the investor's objectives and time horizon, (2) identifying one or more viable alternatives for meeting each objective, (3) evaluating and comparing the viable alternatives, and (4) implementing and monitoring the appropriate investment(s).

For each investment alternative, the analyst must: (1) determine what management activities will occur and in what year, (2) estimate the amount of money that will be spent or received as well as the degree of uncertainty associated with each cash flow estimate, (3) develop a "cash flow" table that places the appropriate amount in the corresponding year of occurrence, (4) determine the minimal acceptable rate of return (MARR) (an interest rate) required by the investor, (5) calculate and analyze measures of financial profitability, and (6) calculate and analyze the uncertainty associated with the alternative. After all investment alternatives have been evaluated, the one(s) that represent the most efficient use of available resources is implemented and monitored.

If you have little or no experience in woodland management or timber marketing, seek the assistance of a professional forester when undertaking these activities. The forester can provide useful information on timber management alternatives as well as current data for the timing and amount of cash flows that could be expected within your locality. Typical costs that may occur when evaluating timber management alternatives include property taxes, consulting fees, and fees for sale preparation and administration. The selling of standing timber is a typical revenue. Other revenues, such as income from a hunting rights lease, could also be included in the cash flow table if appropriate.

Most States publish stumpage price reviews that can be useful for estimating average prices received for harvested timber (Appendix A). However, stumpage is an unusual commodity that has no exact or "going" price. Instead, the selling price is whatever the buyer and seller agree to and is influenced by many factors, including: (1) species, (2) size, (3) quality, (4) volume of sale, (5) distance to market, (6) site accessibility, (7) logging difficulty, (8) market conditions, (9) buyer's log inventory, and (10) seller's restrictions on harvesting and skidding techniques (Blinn and Hendricks 1985). In addition, because stumpage price reviews cover broad geographic areas, you should use reported prices only to obtain a gross estimate of revenues.

Three general types of cash flows are possible in an analysis:

1. **Single occurrence**: an activity that occurs once during the analysis. An example might be to thin at age 40. You must know the year of occurrence and the amount.
2. **Annual occurrence**: an activity that occurs in each year for 2 or more consecutive years with the same cash flow occurring every year. An example might be annual property taxes. You must know the first and last years of occurrence as well as the amount.
3. **Periodic occurrence**: an activity that costs or returns the same amount every year but does not occur in consecutive years (fertilizing with the same rate of application every 5 years) or an activity that may or may not occur in consecutive years with varying cash flows (Christmas tree shearing costs that vary due to annual differences in number of trees per acre and/or tree size). You must know the number of times the activity occurs and the appropriate amount for each year of occurrence.

Interest is a mechanism for equilibrating the supply and demand for investment capital and savings over time. It can also be thought of as the return that can be obtained from the productive investment of capital or the rent (price) that is paid to lenders for use by borrowers. Although you may not need to borrow money to finance your investments, interest concepts are still appropriate when evaluating investments because capital invested in forestry could be used in an alternative investment (for example, a Certificate of Deposit) that may have a different profitability and associated risk.

Most investment analyses use an appropriate "discount rate" to reflect the notion that a dollar today is worth more than the same dollar 10 years from now. Discounting is a procedure that determines the present worth of a future expected cash flow. The discount rate is sometimes known as the *minimum acceptable rate of return* (MARR). The MARR for an analysis should be your cost of capital. Therefore, an investor who can borrow money at 10 percent would specify a MARR of 10 percent. For an investor who is going to use money that is not borrowed, the MARR becomes the interest rate for the investment account where money is being held (e.g., a savings and loan passbook account, a Certificate of Deposit, a bond, etc.) or the interest rate associated with the most financially attractive viable alternative investment.

Your MARR may change as the overall rate of inflation within the economy changes. Discount rates or MARR's that do not incorporate an overall inflation rate are called *real rates*. A discount rate that contains a real component as well as an overall inflation rate for the whole economy is called a *nominal rate*. A discount rate that is developed directly from a rate quoted from a financial savings and/or lending institution is a nominal rate because it incorporates a real rate as well as the economy's inflation rate. Nominal rates are higher than real rates as long as the inflation rate is greater than zero. Many people prefer to conduct an investment analysis using a nominal discount rate because it is relatively easy to calculate a MARR using savings and loan rates available from financial institutions. However, the implied general inflation rate must still be estimated to conduct the proper analysis. An investment analyzed using a real discount rate should not be compared with an alternative assessed with a nominal discount rate.

Individual cash flows may have different rates of inflation than the overall rate assumed in the analysis. As an example, stumpage rates have historically appreciated faster than the overall inflation rate within the economy. An additional inflation rate may be included for stumpage, if it can be determined. Additional inflation rates for other factors are usually not incorporated because these rates are hard to determine.

Various criteria have been developed for evaluating an investment's performance. Some of the investment performance measures include net present value (NPV), equivalent annual income (EAI), soil expectation value (SEV), benefit cost ratio, payback period, and internal rate of return (IRR). Each of these factors is defined below.

1. **Net present value or present net worth (PNW)**.—Present value of expected revenues minus the present value of expected costs, with all costs

and returns discounted at the MARR. NPV cannot be used to directly compare alternatives with different investment lengths. Investments that have a positive NPV will yield a higher financial return than the MARR used in discounting. If everything is equivalent (risk, investment length, initial investment) between two or more investment alternatives, you would generally select the one that yields the higher positive NPV.

2. **Equivalent annual income or equal annual equivalent.**—Net present value converted to an annual value paid at the end of each year over the life of the investment with interest calculated at the MARR. Because EAI is calculated using NPV, its interpretation is similar to NPV when comparing investment alternatives.
3. **Soil expectation value or the Faustmann formula, bare land value, or land expectation value.**—The value of bare forest land, equivalent to the capitalized value of an infinitely long series of cash flows resulting from timber management. SEV represents the maximum amount that could be paid for a tract of land and still earn the MARR. It is useful for estimating the bid price of bare land for growing successive crops of even-aged timber. Because SEV is defined as the value of bare forest land, forest management alternatives must incorporate all cash flows that occur during a complete management rotation, starting with initial site treatments on bare land, to correctly use this investment criterion. Land purchase costs and land sale returns must be removed from an analysis before a meaningful SEV can be computed. If all criterion assumptions are satisfied, SEV is useful when comparing management alternatives that have different rotation lengths. Where SEV can be applied correctly, select the alternative that has the highest value, given equivalent risk and initial investment.
4. **Benefit cost ratio.**—The present value of discounted revenues divided by the present value of discounted costs. A benefit cost ratio greater than one indicates that discounted benefits exceed discounted costs. If everything is equivalent (risk, investment length, initial investment) between two or more investment alternatives, select the one that yields the higher positive benefit cost ratio.
5. **Payback period.**—The length of time needed for an investment's cumulative annual net cash flows to exceed the required initial investment. Cash flows are generally discounted when this factor is calculated. Investments with short payback periods are sometimes considered to have a lower risk because there is more certainty when estimating cash flows that do not occur far into the future.
6. **Internal rate of return.**—The discount rate that equates the present value of discounted costs and revenues, or the discount rate that would make NPV equal zero. IRR is generally calculated using an iterative process to solve for the appropriate discount rate. An IRR smaller than the MARR used in the analysis indicates that the investment's rate of return is less than the MARR (the investment would also yield a negative NPV). IRR's exceeding the MARR reflect an investment whose rate of return will exceed this alternative rate. You would generally select investment(s) with the highest IRR that exceeded the MARR, given equal risk between investments.

The two most frequently used criteria for comparing investments are NPV and IRR. Although all the various evaluation criteria will favor the same investment alternatives when the decision involves comparing opportunities that are independent (at least two alternatives can be chosen), criteria may differ when investment alternatives are mutually exclusive (only one of the feasible candidate investments can be chosen). The IRR criterion is most appropriate when capital is the primary limiting factor (e.g., no more capital can be borrowed) or when alternatives are independent. The NPV criterion is most appropriate when land is the primary limiting factor (e.g., only one parcel of land is being analyzed) or when alternatives are mutually exclusive.

Evaluate the amount of risk or uncertainty associated with each investment cash flow both before and after analyzing each alternative. Risks are noninsurable losses that may occur, such as physical damage, increases in costs, or decreases in product prices. Although there are several methods for accounting for risk in an investment analysis, sensitivity analysis is a common approach to dealing with this uncertainty (Rose *et al.* 1988). Sensitivity analysis is conducted as a part of an investment analysis to evaluate how a specified change in each cash flow affects the various measures of investment performance.

To avoid biasing the investment decision, establish the degree of confidence for every cash flow estimate before performing the investment analysis. Activities considered to be uncertain, either due to a wide range or variability in amount, and those activities identified as critical factors by the sensitivity analysis deserve further special attention.

You may decide to implement one or more alternatives after performing all the appropriate analyses. Monitoring procedures should be conducted during the implementation phase, as well as throughout the life of the investment, to increase the chances of financial success. Monitoring will provide invaluable information about the investment status and profitability as well as data that might be useful when analyzing and/or monitoring other investment alternatives. Further information on investment analysis in general and monitoring procedures in particular may be found in Rose *et al.* (1988).

TWIGS INVESTMENT ANALYSIS

A tool such as TWIGS is useful for predicting future timber yields under alternative management strategies when analyzing forestry investments. The TWIGS Economics Menu is shown in figure 1. TWIGS assumes that all cash flows are entered in base year dollars and that they occur at the beginning of the indicated year. Either a real or a nominal discount rate may be used in the analysis, and inflation rates for individual activities can be included. A single additional inflation rate may be specified for all species-product stumpage prices. TWIGS automatically calculates and enters timber harvesting incomes into the diary of cash flows based on user-defined stumpage rates. An explanation of how costs and incomes other than harvesting revenues are entered into TWIGS can be found in Miner *et al.* (1988). A form for developing a cash flow table, for recording the associated uncertainty. and for reporting other information relevant to a forest management investment alternative is presented in Appendix B.

The various investment analysis tables produced by TWIGS include: (1) a summary of cash flow inputs, (2) an annual cash flow summary (an optional output), (3) an analysis of NPV at even discount rates between 0 and 50 percent, (4) a summary of the six investment evaluation criteria defined above, (5) the sensitivity of NPV, EAI, and SEV to a 10-percent change in the original cash flow value for each investment activity, and (6) the percent change, up to 100 percent, for each cash flow value so that NPV will become exactly zero. Although TWIGS does not automatically perform an after-tax analysis, you should consider this factor when comparing alternatives.

EXAMPLE OF AN INVESTMENT ANALYSIS USING TWIGS

Here is an example of how an investment analysis might be conducted using TWIGS. All the various investment analysis steps are presented for the one alternative analyzed.

Scenario

An investor living in northeastern Minnesota wishes to invest about $15,500 in 1987 with investment liquidation to occur in 2007. Further investment monies will be available during this period. The investor is approaching retirement and wants to maximize returns from investing funds.

```
ECONOMICS MENU:

OPTION   VALUE     DESCRIPTION
  A     $ 29.00    Stumpage rate per 1000 board feet of sawtimber (default value).
  B     $  6.00    Stumpage rate per cord of poletimber (default value).
  C     $   .00    Stumpage rate per 100 Cuft of residue (default value).
  D                Change stumpage rates for a species ( 0 set, 10 available).
  E           0    Annual stumpage price inflation rate (in percent).
  F           0    Set option to display cash flow table
                   0 = Do not display table
                   1 = Display table
  G        1987    Base year for economic analysis (less than or equal to 1987).
  H        7.10    Nominal discount rate (in percent).
           2.00    General inflation rate (in percent).
  I                See, add or edit the diary of cost and revenue
                   activities (per acre).
  J           0    Set option to discount the cash flows.
                   0 = Discount all cash flows through 2007.
                   1 = Do not consider cash flows beyond the
                       current projection year (1987).
  K                Show economic evaluation on screen.
  L                Show economic evaluation on screen & printer.

Type option letter or type  Z  to continue:
```

Figure 1.—*Economics menu for setting TWIGS economic parameters.*

Several different alternatives are identified, each of which may meet the investor's objectives. One alternative is to invest all funds in a risk-free savings account that will yield a 7-percent nominal rate of return, including a 4-percent general inflation rate. This 7-percent nominal rate of return was established as the investor's MARR. A second alternative is to purchase a 40-acre tract of land with a 56-year-old natural stand containing red pine, jack pine, white pine, and paper birch. This second alternative is analyzed using the Lake States version of TWIGS.

Investment Analysis Input

The investor employed a forester to inventory the stand, to compile the data into the form of a tree list required by TWIGS, and to develop an appropriate management plan. The tree list for this natural stand is found in a file named LSTLIST on the Lake States TWIGS distribution diskette. A site index of 55 was recorded for red pine during the 1987 inventory. Each acre in the stand currently contains an average of 308 trees, a basal area of 132.9 square feet, and an average d.b.h. of 8.6 inches. Other stand data are shown in Miner *et al.* (1988).

The forester prescribed a thinning from below (taking the smallest trees first) in 1987 to a residual basal area of 90 square feet per acre. Red pine was favored in the residual stand during this commercial thinning. A clearcut was prescribed in 2007.

Stumpage prices assumed in the analysis were representative of prices received from public land in Minnesota (Minnesota Department of Natural Resources 1986) (Appendix A). The investor and the forester agreed on a 1.2-percent annual stumpage price inflation rate, the average real rate of increase for all species across all public timber sales in Minnesota during 1974-1984[1].

Investment cash flows representative of expected costs and returns for the local area, as well as the associated cash flow uncertainties, were then estimated (Appendix C). The purchase of the tract (buy land) is an example of a single occurrence activity. Property taxes and sale preparation expenses represent annual and periodic occurrence activities, respectively. The sale of the land at the end of the investment represents the income that the investor believes could be received from selling bare land. All costs associated with employing the forester at the beginning of the analysis are included in 1987 sale preparation expenses.

The investor and the forester are fairly certain of the cash flow estimates for the 1987 thinning sale income. Cash flow estimates for the 2007 clearcut sale and the income received due to selling the bare land are both highly uncertain. The investor must pay special attention to these uncertainties when evaluating TWIGS economic analysis outputs.

Investment Analysis Output

The abbreviated TWIGS cash flow table presented in table 1 summarizes a portion of the data necessary to calculate the various measures of investment performance. The table is primarily a listing of the cash flow amounts for each year of the investment, incorporating inflation where appropriate. Four cost and three revenue activities are included in the analysis. The two sale incomes were automatically calculated and entered in table 1 as a result of management treatments prescribed (thin from below to 90 square feet of basal area in 1987, favoring red pine, and clearcut in 2007). Cash flow tables also present total expenditures and receipts and net revenues for each year in the analysis. All cash flows that do not occur in the analysis base year (1987) are inflated by the appropriate rate. Note, for example, that the cash flow associated with the sale income that occurs in 2007 is $2,745.51. This amount was calculated according to the following formula:

$$a\,(1 + gi)^{n-1}\,(1 + ai)^{n-1}$$

where: a = current price in 1987 ((stumpage rate times cut volume), totaled for all species)
gi = general inflation rate (0.04)
ai = additional annual inflation rate (0.012)
n = period of occurrence (21; n−1 = 20).

Therefore, the 2007 "SALE INCOME" cash flow was calculated as:

$$\$987.07(1 + 0.04)^{20}\,(1 + 0.012)^{20} = \$2,745.51.^{2}$$

Table 2 provides a profile of net present values for the investment at various discount rates. This allows an assessment of the effect of different discount rates on net present value. The column displaying nominal discount rates would not appear in a real analysis.

---

[1] *Personal communication with D. Ford, Economist, Minnesota Department of Natural Resources, Division of Forestry, St. Paul, MN.*

[2] *Hand calculated numbers may not always agree with TWIGS calculations at the hundredth decimal place due to rounding differences.*

Table 1. A portion of the annual cash flow table for the red pine timber management alternative[1]

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

	YEAR				
ITEM	1987	1988	...	2006	2007
Buy Land	300.00	.00	...	.00	.00
Property Tax	.90	.94	...	1.90	1.97
Sale Prep.	65.00	.00	...	.00	142.42
Sale Admin.	22.00	.00	...	.00	48.20
TOT ANN COST	387.90	.94	...	1.90	192.60
CUM TOT COST	387.90	388.84	...	413.80	606.40
Sell Land	.00	.00	...	.00	657.34
SALE INCOME	82.95	.00	...	.00	.00
SALE INCOME	.00	.00	...	.00	2745.51
TOT ANN RECP	82.95	.00	...	.00	3402.85
CUM TOT RECP	82.95	82.95	...	82.95	3485.80
ANN NET REV	-304.95	-.94	...	-1.90	3210.25
CUM NET REV	-304.95	-305.88	...	-330.85	2879.40

[1] SALE INCOME was calculated by TWIGS. Other items (shown in upper and lower case letters) were entered by the user.

Table 2. A portion of the profile of net present values at various discount rates for the red pine timber management alternative, as determined by TWIGS

PROFILE OF NET PRESENT VALUE (NPV) FOR THE INVESTMENT AT VARIOUS DISCOUNT RATES
(INVESTMENT LENGTH = 21 YEARS)

(NPV VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

REAL RATE	NOMINAL RATE	NPV
.00%	4.00%	$ 1143.07
2.00%	6.08%	$ 666.92
4.00%	8.16%	$ 351.89
6.00%	10.24%	$ 141.84
8.00%	12.32%	$ .75
10.00%	14.40%	$ -94.70
12.00%	16.48%	$ -159.69
•	•	•
•	•	•
•	•	•
48.00%	53.92%	$ -306.25
50.00%	56.00%	$ -306.31

The before-tax measures of investment performance are shown in table 3. The nominal internal rate of return would not be displayed if a real analysis had been conducted. All investment performance measures, except internal rate of return, are calculated at the user-specified MARR (7-percent nominal rate in this analysis).

The investment performance measures (table 3) indicate that the investment meets the investor's minimum acceptable rate of return (7-percent nominal rate). In fact, the investment yields a 7-percent nominal rate of return plus $511.61/acre today or $34.02/acre/year over the course of the investment. Discounted benefits exceed discounted costs by a ratio of 2.14 to 1.00. Cumulative net discounted cash flows will recover the initial investment of $304.95/acre ($387.90 in costs minus $82.95 in revenue) for buying the land and paying property taxes, and sale preparation and sale administration expenses after discounting 20 years of cash flows. Finally, the net present value is positive for all real discount rates less than 8.01 percent and for all nominal discount rates less than 12.33 percent. The soil expectation value, although calculated, is not an appropriate economic performance measure for this management alternative because the underlying SEV assumptions have not been met.

Although this investment seems financially attractive, sensitivity analysis data must be interpreted to evaluate the risk associated with this alternative. Table 4 shows the sensitivity of the investment performance measures NPV, EAI, and SEV to a 10-percent change in the input cash flow values for all activities. Increases in costs and/or decreases in revenues decrease NPV, EAI, and SEV by the dollar amounts indicated in the table. Conversely, decreases in costs and/or increases in revenues will increase the performance measures. The larger the dollar amount indicated in table 4, the greater the impact of a 10-percent change in the initial cash flow. As before, SEV criteria were not met for this investment alternative so interpretation of SEV sensitivity analysis data is not appropriate.

In this example, the greatest impact on NPV and EAI would result from changes in revenues associated with the sale income that occurs in 2007 when the stand is clearcut. If revenues received for this activity decreased by 10 percent, NPV would decrease by $70.95/acre and EAI would decrease by $4.72/acre/year. Similarly, NPV would decrease by $16.99/acre and EAI would decrease by $1.13/acre/year if land sale revenues decreased by 10 percent.

Table 3. Summary of economic performance measures at a 7- percent nominal discount rate for the red pine timber management alternative, as determined by TWIGS[1,2]

```
                         INVESTMENT PERFORMANCE ANALYSIS

     NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                        (INVESTMENT LENGTH =  21 YEARS)

        (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

--------------------------------------------------------------------------------
          NET PRESENT VALUE (NPV)                          $   511.61

          EQUIVALENT ANNUAL INCOME (EAI)                   $    34.02

          SOIL EXPECTATION VALUE (SEV)                     $  1179.46

          BENEFIT/COST RATIO                                     2.14

          YEARS TO PAY BACK AT DISCOUNT                    20 YEARS

          REAL INTERNAL RATE OF RETURN                          8.01%

          NOMINAL INTERNAL RATE OF RETURN                      12.33%
--------------------------------------------------------------------------------
```

[1] The real and nominal internal rates of return are calculated independent of the specified discount rate.

[2] Although Soil Expectation Value (SEV) was calculated, this criterion is meaningless because all SEV assumptions were not satisfied.

Table 4. Sensitivity analysis to a 10-percent change in individual activity cash flows for the red pine timber management alternative, as determined by TWIGS[1]

```
                              SENSITIVITY ANALYSIS

          (SENSITIVITY OF PERFORMANCE TO A 10% CHANGE IN INPUT VALUES)
       NOMINAL DISCOUNT RATE =  7.00%     GENERAL INFLATION RATE =  4.00%
                        (INVESTMENT LENGTH =  21 YEARS)

             (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

   ITEM CHANGED          NPV CHANGE         EAI CHANGE         SEV CHANGE
-----------------------------------------------------------------------------
   Buy Land             $        30.00     $        2.00     $        69.16
   Property Tax         $         1.44     $         .10     $         3.33
   Sale Prep.           $        10.18     $         .68     $        23.47
   Sale Admin.          $         3.45     $         .23     $         7.94
=============================================================================
   Sell Land            $        16.99     $        1.13     $        39.16
   SALE INCOME          $         8.30     $         .55     $        19.12
   SALE INCOME          $        70.95     $        4.72     $       163.56
=============================================================================
```

[1] Although a sensitivity analysis for Soil Expectation Value (SEV) was performed, the values displayed are meaningless because all SEV assumptions were not satisfied.

Although the "buy land" activity has the second highest sensitivity shown in table 4, the investor need not be overly concerned about the potential impact on the investment's profitability. This cash flow occurs at the beginning of the investment period and was estimated with certainty.

In addition to relative impacts on the investment performance measures, specific impacts can also be calculated. For example, NPV for the investment was calculated to be $511.61/acre (table 3). If the annual property taxes costs had decreased by 10 percent to $0.81/acre, NPV would be $511.61 + $1.44 or $513.05/acre. The same logic holds for EAI and SEV. On the other hand, if property taxes had increased by 10 percent to $0.99/acre, NPV would decrease by $1.44 to $510.17/acre.

Changes in NPV, EAI, and SEV from variations in several cost and/or revenue cash flows can also be calculated directly from table 4. For example, a 50-percent increase in property taxes would lower NPV by five times the amount of a 10-percent property tax increase (five times $1.44 or $7.20/acre). Combinations of any number of cash flow variations can also be calculated. For example, if all costs were 10 percent higher and all revenues were 15 percent lower than the estimates used in the analysis, NPV would equal $511.61 − $30.00 − $1.44 − $10.18 − $3.45 − 1.5($16.99 + $8.30 + $70.95) = $322.18/acre. In other words, even if the above changes were to occur, the overall investment decision based on NPV would remain the same because the investment becomes attractive in a general sense when NPV is greater than or equal to zero.

Sometimes it is useful to know how much change is necessary in one or more costs and/or revenues to change the investment decision. This information is shown in table 5 using NPV as the investment performance measure with percent change calculated up to 100 percent. In this example, the investor might wish to know how much revenues received from the clearcut in 2007 must decrease to cause NPV to equal zero. This is determined by dividing NPV (table 3) by the corresponding change in that measure (table 4), and then multiplying the result by 10 percent (the percent change specified in table 4). Using 2007 clearcutting income and NPV as an example, the result is the following:

$511.61 / $70.95 = 7.211* 10 percent = 72.11 percent

In other words, a decrease of 72.11 percent for 2007 clearcutting income would result in a NPV of zero. That is, NPV would equal zero if the 2007 clearcutting cash flow were reduced from $2,745.51 to $765.72. The clearcut in 2007 is the only activity that would require less than a 100-percent change in cash

Table 5. Sensitivity analysis showing the percent change in individual activity cash flow, up to a maximum of 100 percent, required to make net present value exactly $0.00 for the red pine timber management alternative, as determined by TWIGS

```
                                RISK ANALYSIS

        (INPUT VALUE CHANGES WHICH WILL MAKE NPV EXACTLY EQUAL TO $0.00)
         NOMINAL DISCOUNT RATE =  7.00%     GENERAL INFLATION RATE =  4.00%
                        (INVESTMENT LENGTH =  21 YEARS)

           (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

     ITEM CHANGED              PERCENT CHANGE          DOLLAR CHANGE
---------------------------------------------------------------------------------
     Buy Land                       100.00%          $           -300.00
     Property Tax                   100.00%          $            -14.43
     Sale Prep.                     100.00%          $           -101.80
     Sale Admin.                    100.00%          $            -34.46
=================================================================================
     Sell Land                     -100.00%          $           -169.87
     SALE INCOME                   -100.00%          $            -82.95
     SALE INCOME                    -72.11%          $           -511.61
=================================================================================


NOTE:  WHEN PERCENT CHANGE EQUALS 100% AND DOLLAR CHANGE IS SMALLER THAN
       $   511.61, THE INPUT VARIABLE WILL NOT ALTER THE OVERALL INVESTMENT
       SELECTION, GIVEN THE CURRENT DECISION CRITERIA.
```

flow to reduce NPV to zero. As an example, if annual property taxes increase by 100 percent (i.e., double) to $1.80/acre/year, NPV would decrease by $14.43/acre to $497.18/acre. Similar calculations can also be performed for EAI and SEV using information presented in tables 3 and 4.

Investment Analysis Decisionmaking

Based solely on an assessment of investment performance measures (table 3), the investor may decide to implement this alternative. However, sensitivity analysis indicates that investment performance is somewhat sensitive to changes in estimated revenues from the clearcut in year 2007. Before performing the analysis, the investor and forester determined that the 2007 clearcutting income cash flow estimate is very uncertain (Appendix C). If any combination of factors, such as poor markets, decreased yield, disease, or lower rates of real stumpage price increase (less than the 1.2 annual percentage rate assumed) were to cause estimates for this cash flow to decrease by more than 72.11 percent, NPV would be less than zero. Any increases in cost activity cash flows without an increase in revenues would further reduce this percentage. The investor should also consider that the actual growth and yields differ from one location to another and TWIGS only provides an estimate of the regional average. Also, because TWIGS only performs a before-tax analysis, the investor would be wise to examine the implications of tax on the investment's performance. This information, combined with the economic performance data (table 3), should be evaluated when comparing this alternative to other potential investment alternatives.

The investor should perform similar analyses for other investment alternatives. Some of these alternatives might involve different management scenarios for the same timber stand. The risk and uncertainty associated with each alternative should be assessed and compared.

An investor who favors safe investments (a risk-averse investor) would probably avoid our example alternative in favor of an investment yielding a secure 7-percent nominal rate of return. Investors who seek returns greater than a secure 7-percent nominal rate of return, even if the risk is greater (risk-neutral or risk-seeking investors), would probably choose to invest in the 40-acre tract of land. If so, the investor should monitor the investment both during implementation and every year before 2007.

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APPENDIX A

SUMMARY OF PUBLISHED STUMPAGE PRICE REVIEWS FOR THE NORTH CENTRAL REGION [1,2]

tate	Title	Source	Publications/Year
llinois	Illinois Timber Prices Survey	IL Dept. of Agriculture Box 19283 Springfield, IL 62794-9283	2
ndiana	Forest Products Marketing and Wood Utilization Report	Dept. of Forestry and Natural Resources Purdue University West Lafayette, IN 47907	4
ichigan	Timber Mart-North	F. W. Norris P.O. Box 1278 Highlands, NC 28741	4
innesota[3]	Public Stumpage Price Review	MN DNR Div. of Forestry 500 Lafayette Road St. Paul, MN 55155	1
issouri[4]	Missouri Log Market Report	Extension Forester Univ. of Missouri-Columbia School of Forestry 1-34 Ag. Bldg. Columbia, MO 65201	4
isconsin	Forest Products Price Review - Boltwood Edition (Boltwood Prices) and Timber Edition (Sawtimber Prices)	Extension Forester Department of Forestry University of Wisconsin 1630 Linden Drive Madison, WI 53706	2 (each bulletin)

---

[1] Iowa does not regularly publish stumpage price reviews.

[2] There may be a cost associated with receiving some of the price reviews.

[3] Only stumpage prices from public timberland are reported.

[4] Only delivered prices at the mill are reported. Logging and transportation costs would need to be deducted from the reported data to determine stumpage prices.

APPENDIX B

INVESTMENT ANALYSIS PREPARATION FORM

Analyst's Name: __________
Date: ___/___/___

1. General Description

Base Year for Analysis: ________

Last Year in Which an Activity Occurs: ________

Investment Size (acres): ____________

Real Discount Rate: __ percent or

Nominal Discount Rate: __ percent and General Inflation Rate: __ percent

2. Activity Descriptions

Number of Cost Activities: ___

Number of Revenue Activities: ___

Activity Name	Annual Inflation Rate (Percent[1])	Type of Occurrence[2]	Year(s) of Occurrence	Cash Flow in Base Year Dollars[3]	Degree of Confidence in Estimate[4]	Comments

---

[1] The percent by which the activity's inflation rate is different from the general inflation rate specified above.

[2] Single (S), annual (A), or periodic (P) occurrence.

[3] Enter cash flows on a per-acre basis with a minus (-) sign for costs and a plus (+ sign for receipts.

[4] Certain (C), fairly certain (FC), uncertain (UC), highly uncertain (HU). The analys may also choose to enter a range or other measure of variability.

APPENDIX B. Investment analysis preparation form (continued)

Analyst's Name: ____________

Date: ___/___/___

ctivity Name	Annual Inflation Rate (Percent[1])	Type of Occurrence[2]	Year(s) of Occurrence	Cash Flow in Base Year Dollars[3]	Degree of Confidence in Estimate[4]	Comments

---

[1] The percent by which the activity's inflation rate is different from the general inflation rate specified above.

[2] Single (S), annual (A), or periodic (P) occurrence.

[3] Enter cash flows on a per-acre basis with a minus (-) sign for costs and a plus (+) sign for receipts.

[4] Certain (C), fairly certain (FC), uncertain (UC), highly uncertain (HU). The analyst may also choose to enter a range or other measure of variability.

APPENDIX C

ECONOMIC INPUTS FOR THE ANALYSIS OF A 56-YEAR-OLD RED PINE STAND

Analyst's Name: R. Forester
Date: 12 /15 /87

1. General Description

Base Year for Analysis: 1987

Last Year in Which an Activity Occurs: 2007

Investment Size (acres): 40 Acres

Real Discount Rate: __ percent or

Nominal Discount Rate: 7 percent and General Inflation Rate: 4 percent

2. Activity Descriptions

Number of Cost Activities: 4

Number of Revenue Activities: 3

Activity Name	Annual Inflation Rate (Percent[1])	Type of Occurrence[2]	Year(s) of Occurrence	Cash Flow in Base Year Dollars[3]	Degree of Confidence in Estimate[4]	Comments
Buy Land	0	S	1987	-300.00	C	--
Property Taxes	0	A	1987-2007	-0.90	FC	Estimates reliable for ne future only.
Sale Prep.	0	P	1987	-65.00	UC	Estimates reliable for ne future only.
			2007	-65.00		Dependent on cost & availability of la

---

[1] The percent by which the activity's inflation rate is different from the general inflation rate specified above.

[2] Single (S), annual (A), or periodic (P) occurrence.

[3] Enter cash flows on a per-acre basis with a minus (-) sign for costs and a plus (+) sign for receipts.

[4] Certain (C), fairly certain (FC), uncertain (UC), highly uncertain (HU). The analyst may also choose to enter a range or other measure of variability.

PENDIX C. Economic inputs for the analysis of a 56-year-old red pine stand (continued)

Analyst's Name: R. Forester
Date: 12 /15 /87

neral Description

tivity Name	Annual Inflation Rate (Percent[1])	Type of Occurrence[2]	Year(s) of Occurrence	Cash Flow in Base Year Dollars[3]	Degree of Confidence in Estimate[4]	Comments
le min.	0	P	1987	-22.00	UC	Estimates reliable for near future only.
			2007	-22.00		Dependent on cost & availability of labor
ll nd	0	S	2007	+300.00	HU	Uncertainty in future market for land.
le come[5]	1.20	S	1987	+82.95	FC	--
le come[5]	1.20	S	2007	+987.07	HU	Uncertainty in future prices and markets

---

The percent by which the activity's inflation rate is different from the general inflation rate specified above.

Single (S), annual (A), or periodic (P) occurrence.

Enter cash flows on a per-acre basis with a minus (-) sign for costs and a plus (+) sign for receipts.

Certain (C), fairly certain (FC), uncertain (UC), highly uncertain (HU). The analyst may also choose to enter a range or other measure of variability.

Sale income revenues are automatically calculated by the ECON subroutine in TWIGS and entered into the diary of cost and revenue activities.

Blinn, Charles R.; Rose, Dietmar W.; Belli, Monique L.
1988. Guide to analyzing investment options using TWIGS. Gen. Tech. Rep. NC-123. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 15 p.

Describes methods for analyzing economic return of simulated stand management alternatives in TWIGS. Defines and discusses net present value, equivalent annual income, soil expectation value, and real *vs.* nominal analyses. Discusses risk and sensitivity analysis when comparing alternatives.

KEY WORDS: Economic analysis, simulation, financial uncertainty, sensitivity analysis, risk.

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North Central
Forest Experiment
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General Technical
Report **NC-124**

Evaluation of Resources at Risk from Wildland Fires

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Manuscript approved for publication June 13, 1988
1988

EVALUATION OF RESOURCES AT RISK FROM WILDLAND FIRES

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and
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To properly allocate wildfire control resources among various wildland fire control districts of a State, it is necessary to estimate the value at risk from wildfire for each district and to compare them. We define value at risk as the value of resources (principally timber or structures) that can be damaged or destroyed by wildfire. Value at risk is always larger than net value change—the actual net loss or gain experienced as the result of wildfire. To estimate value at risk precisely would require careful examination of fire occurrence and value change data, normalized for variation in weather and protection effort, for the full range of wildland resources over a fairly long time. In most States, good records of the number and size class of wildfires and the acreage burned for counties and regions are available for a sufficient time span to make adequate estimates of fire activity, given past weather patterns and levels of protection effort. Records of value change have, however, always been sketchy. Recent studies (Crosby 1977, Marty and Barney 1981, Althaus and Mills 1982, Gorte and Baumgartner 1983) have identified the various value components, including non-market values, that can be affected by fire and have suggested methods to measure each. However, until these methods are implemented and better value change data are collected over at least several years, less precise methods must be used. At this point the limitations of existing value change data preclude the practical application of precise analyses of value at risk from wildfire. A precise analysis should be complete with measures of both market and non-market resource values and potential value changes (including beneficial ones) that fires may cause. We know what should be in a comprehensive model of value at risk, but are only beginning to collect the input necessary to develop accurate probability estimates for a wide range of possible events and outcomes. In the short term, the best possible use must be made of existing information. The objective of this paper is to show how existing information can be used to establish values for timber and structures and to assess the potential for large wildland fires in representative counties of northern lower Michigan. These values combined with an assessment of the potential for large fires can then be used to provide a preliminary indicator of where fire protection efforts should be concentrated.

THE MICHIGAN FOREST FIRE ECONOMIC ANALYSIS

In 1984, the Forest Management Division of the Michigan Department of Natural Resources prepared an economic analysis (Siegle 1984) to help determine the preferred budget level for the Michigan Forest Fire Program. The analysis used the Initial Attack Assessment (IAA) model from the National Fire Management Analysis System (NFMAS) of the USDA Forest Service to develop cost plus net value change (C+NVC) options for 19 fire protection areas in the northern two-thirds of Michigan. Various budget levels (costs) were projected to result in certain value changes (NVC's) until a minimum C+NVC level was determined for each fire management analysis zone (FMAZ). The results showed that achieving the minimum C+NVC would require lower budgets in nine of the FMAZ's, higher ones in six, and no change in four, suggesting the need for reallocating some then existing budget funds among zones. Since then, all locations for which the minimum C+NVC was below the present budget in

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1983 have lost additional personnel and no longer show that advantage. Still the analysis is useful in determining where to place "soon to be hired" personnel. This analysis incorporated the major elements of a good value at risk model. Fire history and weather records, as well as the presuppression (fixed) and actual initial attack suppression (variable) costs, were determined. Representative fires were chosen, and typical initial attack responses to them were developed. The cost element in the C+NVC function was well defined. However, although the analysis may have done a good job of projecting the acreages of various types of stands that would be killed or injured at alternative budget levels, a good historical record of NVC associated with given types of fires was not available. The analysts had to do the best they could at improvising estimates of the NVC of timber, improvements, recreation, and wildlife with bits and pieces of information from a variety of sources, including other States and the opinions of experienced researchers and fire managers.

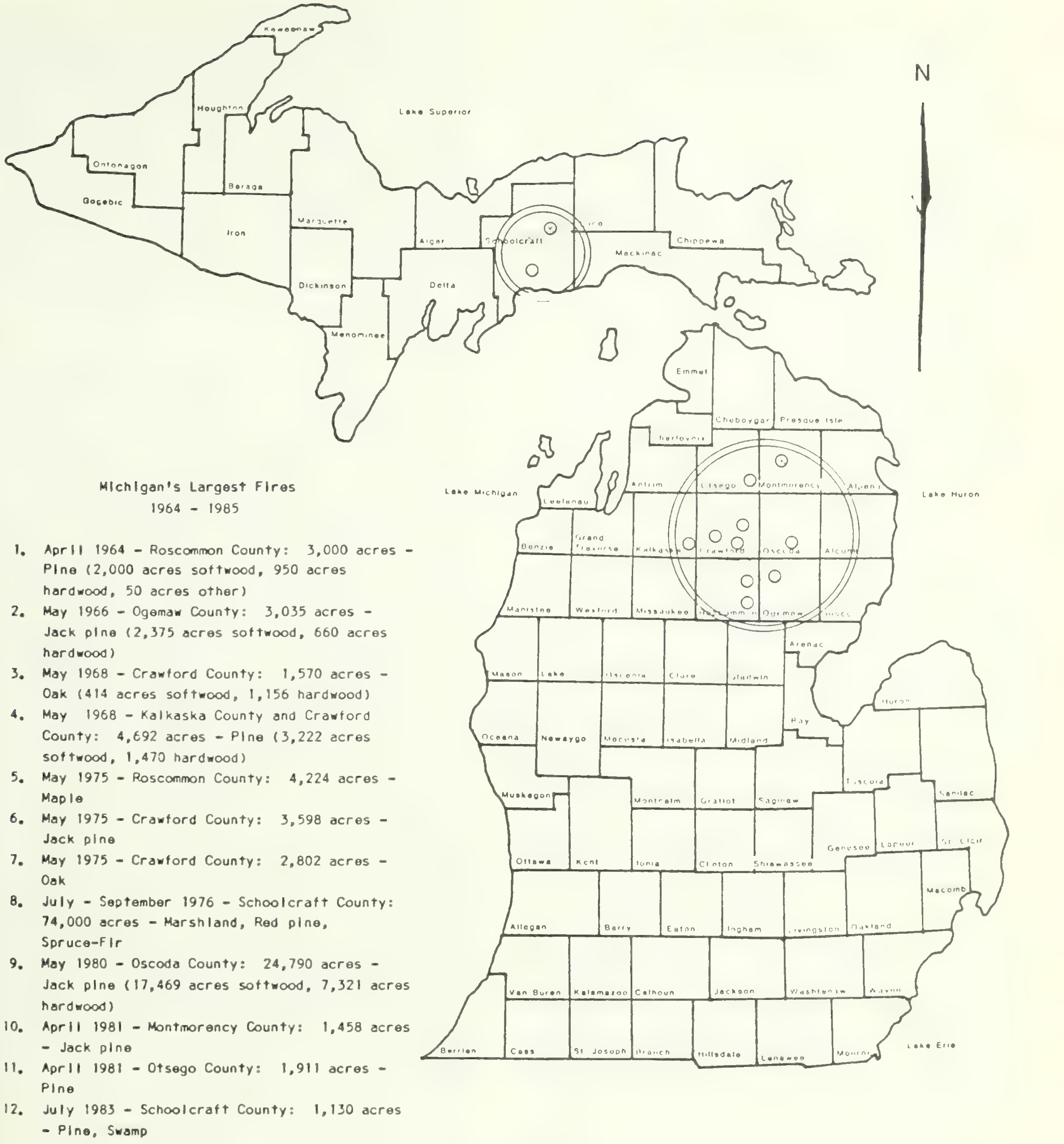
In 1985 a task force was appointed by the Chief of the Forest Management Division of the Michigan Department of Natural Resources to review the analysis and apply the results to see how the present allocation of fire protection effort would be affected. The task force found that the C+NVC analysis suggested funding levels and reallocations that agreed with its intuitive, collective judgment and that it could be used in allocating protection effort. The task force also suggested that the value change data should be improved and accumulated by using the best available appraisal methods when completing individual fire report forms. In retrospect, several sources of information can be identified and used to supplement the economic analysis until improved NVC data are collected for a sufficient number of representative individual fires.

TIMBER

In the Michigan Economic Analysis, timber resources were broadly grouped by species as mature or developing pine, jack pine, hardwood, or aspen. Statewide average values were estimated for each of the species-size groups and then weighted according to their proportion in a given protection unit to arrive at a "composite acre" value. This value is applied to each acre projected to burn in the protection unit, based on the 10-year fire history in the unit. This information can be supplemented with data from two Michigan forest surveys (Pfeifer and Spencer, n.d., Jakes 1982) to obtain a measure of timber volume change between 1966 and 1980 as well as an estimate of the present volume. Applying 1984 timber prices to both sets of survey data yields value change data (tables 1-6). The tables provide examples for Region 2 (the northern Lower Peninsula) as well as for five individual counties within the Region. The value and value change data are summarized in tables 7 and 8. One can quickly see from the tables that timber values (in 1984 dollars) have increased markedly in all five counties and in Region 2. Of the five counties, both Roscommon and Charlevoix had larger percent value increases per acre of commercial forest land than Region 2 as a whole. Clare, Crawford, and Cheboygan had somewhat smaller increases. Roscommon County, where timber value per acre of commercial forest land increased about 133 percent between 1966 and 1980, stands out as far above average.

Estimates of the timber value at risk from wildfire can also be made more accurate by examining fire history, particularly for the relatively few largest fires that account for a high percentage of the acreage burned and volume and value of timber damaged. Figure 1 shows the distribution by county of all fires more than 1,000 acres that occurred in Michigan during 1964-1985. It is clear that most of the largest fires occurred in a cluster of counties in the northern Lower Peninsula of Michigan and in one county in the Upper Peninsula. The Upper Peninsula case was the State's largest modern fire. It may be something of an aberration because it was discovered when small and watched for many days before being attacked aggressively, but belatedly, due to jurisdictional policy differences. In general, its large size seems to be the result of a highly unlikely combination of physical and institutional circumstances. Figure 1 also gives an idea of timber types most likely to be involved in the largest fires. Pines, especially jack pine, seem to be the most fire prone, but hardwoods are not exempt from large fires.

Fire history statistics can be misleading in predicting future fires, as may be the case involving Michigan's largest fire in recent years, which under most circumstances would have stayed small. An absence of large fires could be the result of unusual weather conditions or of exceptionally effective prevention and initial attack activities. In this case fuels could be building up to the point where the future danger could be much higher than the past would indicate. Still, the historical record of large fires, when included with other data discussed in this paper, can help provide an improved estimate of value at risk. During 1964-1985, Crawford and Roscommon Counties had the highest incidence of large fires of any Michigan counties, standing apart even within the cluster of large fire-prone counties in the northern Lower Peninsula. Higher timber values in Roscom-



Michigan's Largest Fires
1964 - 1985

1. April 1964 - Roscommon County: 3,000 acres - Pine (2,000 acres softwood, 950 acres hardwood, 50 acres other)
2. May 1966 - Ogemaw County: 3,035 acres - Jack pine (2,375 acres softwood, 660 acres hardwood)
3. May 1968 - Crawford County: 1,570 acres - Oak (414 acres softwood, 1,156 hardwood)
4. May 1968 - Kalkaska County and Crawford County: 4,692 acres - Pine (3,222 acres softwood, 1,470 hardwood)
5. May 1975 - Roscommon County: 4,224 acres - Maple
6. May 1975 - Crawford County: 3,598 acres - Jack pine
7. May 1975 - Crawford County: 2,802 acres - Oak
8. July - September 1976 - Schoolcraft County: 74,000 acres - Marshland, Red pine, Spruce-Fir
9. May 1980 - Oscoda County: 24,790 acres - Jack pine (17,469 acres softwood, 7,321 acres hardwood)
10. April 1981 - Montmorency County: 1,458 acres - Jack pine
11. April 1981 - Otsego County: 1,911 acres - Pine
12. July 1983 - Schoolcraft County: 1,130 acres - Pine, Swamp

Figure 1.—*Michigan's largest fires, 1964-1985.*

mon County, together with the high incidence of large fires, reinforce the indication of high potential value at risk.

A third indicator of timber value at risk from wildfire is the spatial arrangement of forest cover in a given area. The possibility of large fires is limited to areas that have large continuous acreages of fire-prone timber types. Aerial photography and satellite imagery can show the continuity of fuels at various levels of resolution. Landsat cover type maps show that important county differences in the continuity of coniferous and deciduous tree cover can easily be seen. These maps are produced in color and brilliantly show the continuity of forest cover as well as urban and built-up land, crop land, range land, inland water, forested and non-forested wetlands, and barren land.

Crawford County shows more or less complete continuous forest cover with coniferous types predominating. Roscommon County also shows extensive continuous forest coverage with roughly equal proportions of coniferous and deciduous species. Charlevoix County indicates a fragmented pattern of deciduous forest with much smaller areas of continuous cover. It seems clear that Roscommon and Crawford Counties have higher timber values at risk from wildfire than does Charlevoix, and that Roscommon County has the highest value at risk when the three factors of timber value per acre, large fire history, and continuity of forest cover are considered.

IMPROVEMENTS

Potential damage to improvements including structures and their contents, equipment, and ornamental trees should be included in an analysis of value at risk. Improvements are becoming an increasingly important component of value at risk as the area of rural-urban interface and the popularity of rural living increase in fire-prone areas. The Michigan Economic Analysis (Siegle 1984) developed a figure of $72.00 per acre as an average improvement damage cost per acre burned. This figure was used on a statewide basis. Data available from county tax records can show that variation in improvement values between counties and/or "protection areas" exist, and they can be used to provide another indicator of value at risk that should be considered along with factors affecting values at risk to timber. Table 9 provides data on the approximate equalized value of land and improvements in 1967 and 1985 for the five study counties in the northern Lower Peninsula. Although these figures do not isolate improvements, except for Roscommon County in 1985, they reflect large county differences in improvement values and rates of change. When used in conjunction with the factors for estimating values at risk to timber, they can improve the estimate of county or "protection area" variation in value at risk from wildfire. Table 9 indicates that Charlevoix and Roscommon Counties have the highest per acre values for land and improvements, and both have high timber values. Charlevoix County, however, has no recent history of large fires and a fragmented pattern of forest cover, which is primarily deciduous species. Roscommon County, on the other hand, has a record of large fires and a lot of continuous forest cover in fire-prone timber types. It continues to stand out as an example of high value at risk when improvement values enter the picture. Crawford County, with presently low, but rapidly increasing, per acre values for land and improvements, a record of large fires, and a very large area of continuous forest cover, shows a rapidly increasing value at risk.

The Michigan Department of Natural Resources is currently completing a study of improvement values in fire-prone areas, using a sample of individual properties. This will provide a more precise indicator of improvement values at risk from wildfire.

OTHER RESOURCES

Timber and improvement values are the most important components of value at risk and the easiest to estimate in dollar terms. The Michigan Economic Analysis (Siegle 1984) also estimated a value at risk for recreation in each of its "protection units," which consist of all or parts of one to four counties. These per acre values for the "protection units" could be estimated for individual counties to provide another indicator of value at risk on a county basis, or new data could be developed using the Michigan Economic Analysis methodology. It would be more difficult to aggregate the county data, used as value at risk indicators for timber and improvements in this paper, into DNR "protection units" because the "protection units" often include fractions of counties.

Wildlife values need not be considered at risk from wildfire. Information developed in pilot tests of the recently implemented fire effects appraisal system in Wisconsin (Baumgartner 1984) showed that the net economic effect on wildlife was beneficial on 341 of 345 Wisconsin fires and that a net loss occurred on only four. The Michigan Forest Fire Economic Analysis (Siegle 1984) estimated that wildfire impacts on wildlife in Michigan were beneficial on fires less than 100 acres and neutral for those more than 100 acres. Only in a few special circumstances, such as in waterfowl nesting areas in the spring, does wildfire have harmful effects on wildlife.

Data from Wisconsin and Michigan indicate that water quality and soil stability are rarely significantly affected by fires in these States. However, air quality can be affected. The potential impact of fire on air quality for a county generally depends on the number and size of cities and towns, important highways, and recreational developments. If information on these were collected, a subjective estimate of value at risk could be made.

Farm crops, usually hay, are sometimes affected by wildfires. Value at risk to crops could be estimated using Census of Agriculture figures for county acreage in hay and the net value of expected yield (as estimated by county agents).

One other potential indicator of value at risk from wildfire is the cost of rehabilitating burned over forest land. This would differ from county to county depending on timber type and terrain. State forest managers could provide data on this indicator of value at risk. Rehabilitation costs may well be as important as timber and improvement losses.

SUMMARY

This report is intended to show how four types of information can be combined to give a preliminary idea of comparative value at risk from wildfire in five counties in northern lower Michigan. Of the four indicators, timber stumpage values are the most adequately estimated because they are based on a relatively recent timber inventory by the USDA Forest Service. These values account for most losses from wildfire in Michigan. Improvement values are less adequately represented and are growing in importance. This component of value at risk needs further study. The forest management division of the Michigan Department of Natural Resources is currently working to provide accurate estimates of improvement values associated with fire-prone areas. Using only the largest fires for a fire history base also has limitations because smaller fires associated with debris burning may have a larger per acre impact on improvements than the larger ones. More complete information on the spatial frequency and variability of wildfires could be assembled from Michigan wildfire records. The landcover class maps also give only a very general indicator of the continuous forest cover that allows a fire to become large. They too could be refined. Still, easily established rough value estimates for timber and improvements, the recent history of large fires, and the area occupied by continuous fire-prone land cover types can be used to indicate where fire control efforts should be concentrated. Fire managers could use their special knowledge and experience to refine the indicators and to vary the weight for each. They could also consider the potential for wildfire damage to non-market values particular to their jurisdictions.

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Table 1.--Region 2--Northern Lower Peninsula, Michigan, timber inventory

(1984 dollars)

	1966 Sawtimber			1980 Sawtimber		
Species	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	494,100	66	32,610,600	811,402	66	53,552,532
Red pine	224,510	68	15,266,680	1,053,736	68	71,654,048
Jack pine	136,610	26	3,551,860	684,828	26	17,805,528
White spruce	78,360	20	1,567,200	121,852	20	2,437,040
Black spruce	20,460	20	409,200	41,690	20	833,800
Balsam fir	132,460	30	3,973,800	151,930	30	4,557,900
Hemlock	431,120	36	15,520,320	252,871	36	9,103,356
Tamarack	19,380	24	465,120	56,260	24	1,350,240
N. white cedar	420,100	36	15,123,600	653,206	36	23,515,416
Other softwoods	--	20	--	11,647	20	232,940
Total	1,957,100		88,488,380	3,839,422		185,042,800
HARDWOODS						
Select white oaks	335,600	160	53,696,000	572,193	160	91,550,880
Select red oaks	1,107,790	205	227,096,950	2,159,690	205	442,736,450
Other red oaks	511,410	40	20,456,400	488,102	40	19,524,080
Hickory	32,900	40	1,316,000	5,588	40	223,520
Yellow birch	54,610	75	4,095,750	77,578	75	5,818,350
Hard maple	896,230	108	96,792,840	1,188,575	108	128,366,100
Soft maple	667,170	69	46,034,730	1,450,072	69	100,054,968
Beech	594,180	64	38,027,520	389,470	64	24,926,080
Ash	285,600	177	50,551,200	487,434	177	86,275,818
Balsam poplar	353,430	66	23,326,380	353,766	66	23,348,556
Cottonwood	161,810	38	6,148,780	42,830	38	1,627,540
Bigtooth aspen	679,220	37	25,131,140	1,339,410	37	49,558,170
Quaking aspen	731,620	37	27,069,940	1,366,066	37	50,544,442
Basswood	549,110	124	68,089,640	834,836	124	103,519,664
Black cherry	74,270	--	--	172,403	--	--
Elm	1,025,510	62	63,581,620	44,130	62	2,736,060
Paper birch	262,270	46	12,064,420	233,758	46	10,752,868
Other hardwoods	29,460	40	1,178,400	36,859	40	1,474,360
Total	8,352,190		764,657,710	11,242,760		1,143,037,906
All Sawtimber	10,309,290		853,146,090	15,082,182		1,328,080,706
Pulpwood (cords)[5]	47,807,089	$5/cord	239,035,445	53,127,962	$5/cord	265,639,810
			Total value = 1,092,181,535			Total value = 1,593,720,516

Value per commercial forest land acre: $1,092,181,535/6,994,000 acre = $156.16/acre	Value per commercial forest land acre: $1,593,720,516/6,694,900 acres = $238.05/acre

[1] Pfeifer, Ray E.; Spencer, John S., Jr. No date. The growing timber resources of Michigan: Northern Lower Peninsula. Lansing, MI: Michigan DNR. 112 p.

[2] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[3] Jakes, Pamela J. 1982. Timber resources of Michigan's Northern Lower Peninsula, 1980. Resour. Bull. NC-62. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 120 p.

[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 2.--Charlevoix County, Michigan, timber inventory

(1984 dollars)

Species	1966 Sawtimber			1980 Sawtimber		
	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	11,010	66	726,660	25,044	66	1,652,904
Red pine	4,160	68	282,880	14,378	68	977,704
Jack pine	850	26	22,100	2,276	26	59,176
White spruce	1,560	20	31,200	14,936	20	298,720
Black spruce	320	20	6,400	1,111	20	22,220
Balsam fir	3,590	30	107,700	3,803	30	114,090
Hemlock	19,680	36	708,480	8,540	36	307,440
Tamarack	490	24	11,760	833	24	19,992
N. white cedar	14,300	36	514,800	30,721	36	1,105,956
Other softwoods	--	20	--	--	20	--
Total	55,960		2,411,980	101,642		4,558,202
HARDWOODS						
Select white oaks	6,390	160	1,022,400	--	160	--
Select red oaks	26,220	205	5,375,100	11,494	205	2,356,270
Other red oaks	6,330	40	253,200	--	40	--
Hickory	2,050	40	82,000	--	40	--
Yellow birch	1,870	75	140,250	11,662	75	874,650
Hard maple	45,510	108	4,915,080	97,973	108	10,581,084
Soft maple	18,090	69	1,248,210	19,884	69	1,371,996
Beech	32,460	64	2,077,440	30,002	64	1,920,128
Ash	10,970	177	1,941,690	28,384	177	5,023,968
Balsam poplar	8,970	66	592,020	9,081	66	599,346
Cottonwood	4,750	38	180,500	--	38	--
Bigtooth aspen	19,970	37	739,890	30,652	37	1,134,124
Quaking aspen	19,940	37	737,780	56,993	37	2,108,741
Basswood	24,660	124	3,057,840	65,258	124	8,091,992
Elm	34,510	62	2,139,620	3,967	62	245,954
Paper birch	7,040	46	323,840	41,504	46	1,909,184
Black cherry	3,810	--	--	--	--	--
Other hardwoods	990	40	39,600	--	40	--
Total	274,530		24,866,460	406,854		36,217,437
All Sawtimber	330,490		27,278,440	508,496		40,775,639
Pulpwood (cords)[5]	1,359,810	$5/cord	6,799,050	1,704,974	$5/cord	8,524,870
		Total value =	34,077,490		Total value =	49,300,509

Value per commercial forest land acre:
$34,077,490/161,700 acre = $210.75/acre

Value per commercial forest land acre:
$49,300,509/138,600 acres = $355.70/acre

[1] Pfeifer, Ray E.; Spencer, John S., Jr. No date. The growing timber resources of Michigan: Northern Lower Peninsula. Lansing, MI: Michigan DNR. 112 p.

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[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 3.--Cheboygan County, Michigan, timber inventory

(1984 dollars)

Species	1966 Sawtimber			1980 Sawtimber		
	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	27,970	66	1,846,020	44,688	66	2,949,408
Red pine	10,470	68	711,960	65,438	68	4,449,784
Jack pine	7,540	26	196,040	20,651	26	536,926
White spruce	5,880	20	117,600	36,888	20	737,760
Black spruce	1,680	20	33,600	2,975	20	59,500
Balsam fir	8,840	30	265,200	17,187	30	515,610
Hemlock	20,200	36	727,200	13,349	36	480,564
Tamarack	1,060	24	25,440	4,069	24	97,656
N. white cedar	25,480	36	917,280	60,703	36	2,185,308
Other softwoods	--	20	--	--	20	--
Total	109,120		4,840,340	265,948		12,012,516
HARDWOODS						
Select white oaks	12,340	160	1,974,400	1,783	160	285,280
Select red oaks	40,340	205	8,269,700	30,142	205	6,179,110
Other red oaks	19,560	40	782,400	1,848	40	73,920
Hickory	880	40	35,200	--	40	--
Yellow birch	3,010	75	225,750	4,337	75	325,275
Hard maple	31,690	108	3,422,520	48,252	108	5,211,216
Soft maple	34,970	69	2,412,930	24,600	69	1,697,400
Beech	19,350	64	1,238,400	21,656	64	1,385,984
Ash	12,590	177	2,228,430	13,395	177	2,370,915
Balsam poplar	20,210	66	1,333,860	22,722	66	1,499,652
Cottonwood	6,660	38	253,080	--	38	--
Bigtooth aspen	31,430	37	1,162,910	61,771	37	2,285,527
Quaking aspen	36,220	37	1,340,140	129,876	37	4,805,412
Basswood	21,060	124	2,611,440	84,727	124	10,506,148
Elm	50,430	62	3,126,660	1,150	62	71,300
Paper birch	14,280	46	656,880	18,981	46	873,126
Black cherry	2,660	--	--	--	--	--
Other hardwoods	1,340	40	53,600	878	40	35,120
Total	359,020		31,128,300	466,118		37,605,385
All Sawtimber	468,140		35,968,640	732,066		49,617,901
Pulpwood (cords)[5]	2,293,835	$5/cord	11,469,175	3,020,620	$5/cord	15,103,100
		Total value =	47,437,815		Total value =	64,721,001

Value per commercial forest land acre:
$47,437,815/337,200 acre = $140.68/acre

Value per commercial forest land acre:
$64,721,001/366,600 acres = $176.54/acre

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[2] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

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[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 4.--Clare County, Michigan, timber inventory

(1984 dollars)

	1966 Sawtimber			1980 Sawtimber		
Species	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	15,191	66	1,002,540	25,564	66	1,687,224
Red pine	6,650	68	452,200	14,619	68	994,092
Jack pine	1,580	26	41,080	27,530	26	715,780
White spruce	2,290	20	45,800	--	20	--
Black spruce	590	20	11,800	--	20	--
Balsam fir	4,340	30	130,200	1,453	30	43,590
Hemlock	15,570	36	560,520	844	36	30,384
Tamarack	730	24	17,520	4,833	24	115,992
N. white cedar	12,730	36	458,280	12,365	36	445,140
Other softwoods	--	20	--	--	20	--
Total	59,670		2,719,940	87,208		4,032,202
HARDWOODS						
Select white oaks	9,420	160	1,507,200	42,295	160	6,767,200
Select red oaks	32,250	205	8,062,500	112,577	205	23,078,285
Other red oaks	12,240	40	489,600	34,620	40	1,384,800
Hickory	1,190	40	47,600	1,224	40	48,960
Yellow birch	2,170	75	162,750	--	75	--
Hard maple	36,840	108	3,978,720	7,863	108	849,204
Soft maple	32,100	69	2,214,900	49,525	69	3,417,225
Beech	23,500	64	1,504,000	5,516	64	353,024
Ash	11,560	177	2,046,120	7,143	177	1,264,311
Balsam poplar	12,660	66	835,560	5,207	66	343,662
Cottonwood	7,600	38	288,800	2,085	38	79,230
Bigtooth aspen	26,720	37	988,640	61,966	37	2,292,742
Quaking aspen	29,940	37	1,107,780	42,130	37	1,558,810
Basswood	24,620	124	3,052,880	2,140	124	265,360
Black cherry	3,050	--	--	3,660	--	--
Elm	44,810	62	2,778,220	--	62	--
Paper birch	8,470	46	389,620	5,440	46	250,240
Other hardwoods	1,250	40	50,000	1,068	40	42,720
Total	320,390		29,504,890	384,459		41,995,773
All Sawtimber	380,060		32,224,830	471,667		46,027,975
Pulpwood (cords)[5]	1,639,848	$5/cord	8,199,240	1,476,151	$5/cord	7,380,755
		Total value =	40,424,070		Total value =	53,408,730

Value per commercial forest land acre:
$40,424,070/229,000 acre = $176.52/acre

Value per commercial forest land acre:
$53,408,730/215,700 acres = $247.61/acre

[1] Pfeifer, Ray E.; Spencer, John S., Jr. No date. The growing timber resources of Michigan: Northern Lower Peninsula. Lansing, MI: Michigan DNR. 112 p.

[2] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[3] Jakes, Pamela J. 1982. Timber resources of Michigan's Northern Lower Peninsula, 1980. Resour. Bull. NC-62. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 120 p.

[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 5.--Crawford County, Michigan, timber inventory

(1984 dollars)

	1966 Sawtimber			1980 Sawtimber		
Species	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	17,350	66	1,145,100	20,658	66	1,363,428
Red pine	7,640	68	519,520	73,930	68	5,027,240
Jack pine	16,270	26	423,020	100,801	26	2,620,826
White spruce	2,150	20	43,000	--	20	--
Black spruce	460	20	9,200	2,536	20	50,720
Balsam fir	3,050	30	91,500	1,298	30	38,940
Hemlock	7,790	36	280,440	5,038	36	151,140
Tamarack	740	24	17,760	1,467	24	35,208
N. white cedar	9,070	36	326,520	2,834	36	102,024
Other softwoods	--	20	--	222	20	4,440
Total	64,520		2,856,060	208,784		9,393,966
HARDWOODS						
Select white oaks	19,720	160	3,155,200	13,968	160	2,234,880
Select red oaks	57,580	205	11,803,900	105,148	205	21,555,340
Other red oaks	36,990	40	1,479,600	12,075	40	483,000
Hickory	400	40	16,000	--	40	--
Yellow birch	1,390	75	104,250	--	75	--
Hard maple	16,490	108	1,780,920	7,858	108	848,664
Soft maple	14,330	69	988,770	4,482	69	309,258
Beech	11,040	64	706,560	6,515	64	416,960
Ash	6,290	177	1,113,330	882	177	156,114
Balsam poplar	8,000	66	528,000	2,061	66	136,026
Cottonwood	3,810	37	144,780	--	38	--
Bigtooth aspen	17,440	37	645,280	22,958	37	849,446
Quaking aspen	18,630	37	689,310	8,361	37	309,357
Basswood	12,230	124	1,516,520	18,236	124	2,261,264
Black cherry	2,080	--	--	--	--	--
Elm	21,010	62	1,302,620	--	62	--
Paper birch	6,920	46	318,320	12,656	46	582,176
Other hardwoods	670	40	26,800	--	40	--
Total	255,020		26,320,160	215,200		30,142,485
All Sawtimber	319,540		29,176,220	423,984		39,536,451
Pulpwood (cords)[5]	1,792,911	$5/cord	8,964,555	1,966,848	$5/cord	9,834,240
			Total value = 38,140,775			Total value = 49,370,691

Value per commercial forest land acre:	Value per commercial forest land acre:
$38,140,775/303,600 acre = $125.63/acre	$49,370,691/272,900 acres = $180.91/acre

[1] Pfeifer, Ray E.; Spencer, John S., Jr. No date. The growing timber resources of Michigan: Northern Lower Peninsula. Lansing, MI: Michigan DNR. 112 p.

[2] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[3] Jakes, Pamela J. 1982. Timber resources of Michigan's Northern Lower Peninsula, 1980. Resour. Bull. NC-62. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 120 p.

[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 6.--Roscommon County, Michigan, timber inventory

(1984 dollars)

Species	1966 Sawtimber			1980 Sawtimber		
	Volume[1]	Value	Total value[2]	Volume[3]	Value	Total value[4]
	Mbf	$/Mbf	Dollars	Mbf	$/Mbf	Dollars
SOFTWOODS						
White pine	20,080	66	1,325,280	54,771	66	3,614,886
Red pine	6,280	68	427,040	92,722	68	6,305,096
Jack pine	8,060	26	209,560	48,423	26	1,258,998
White spruce	4,610	20	92,200	--	20	--
Black spruce	1,100	20	22,000	776	20	15,520
Balsam fir	6,780	30	203,400	5,359	30	160,770
Hemlock	12,230	36	440,280	434	36	15,624
Tamarack	770	24	18,480	1,533	24	36,792
N. white cedar	22,510	36	810,360	51,881	36	1,867,716
Other softwoods	--	20	--	--	20	--
Total	82,420		3,548,600	255,899		13,275,402
HARDWOODS						
Select white oaks	15,030	160	2,404,800	32,579	160	5,212,640
Select red oaks	48,300	205	9,901,500	186,523	205	38,237,215
Other red oaks	26,390	40	1,055,600	1,414	40	56,560
Hickory	510	40	20,400	--	40	--
Yellow birch	1,480	75	111,000	1,009	75	75,675
Hard maple	17,440	108	1,883,520	--	108	--
Soft maple	17,670	69	1,219,230	43,345	69	2,990,805
Beech	10,990	64	703,360	--	64	--
Ash	7,200	177	1,274,400	9,775	177	1,730,175
Balsam poplar	14,450	66	953,700	7,329	66	483,714
Cottonwood	5,130	38	194,940	--	--	--
Bigtooth aspen	21,510	37	795,870	57,657	37	2,133,309
Quaking aspen	24,040	37	889,480	67,189	37	2,485,993
Basswood	11,970	124	1,484,280	8,933	124	1,107,692
Black cherry	1,680	--	--	--	--	--
Elm	25,130	62	1,558,060	--	62	--
Paper birch	10,440	46	480,240	--	46	--
Other hardwoods	1,010	40	40,400	8,674	40	346,960
Total	260,370		24,970,780	424,427		54,860,738
All Sawtimber	342,790		28,519,380	680,326		68,136,140
Pulpwood (cords)[5]	1,825,323	$5/cord	9,126,615	2,375,178	$5/cord	11,875,890
		Total value =	37,645,995		Total value =	80,012,030

Value per commercial forest land acre:
$37,645,995/269,900 acre = $139.48/acre

Value per commercial forest land acre:
$80,012,030/246,700 acres = $324.33/acre

[1] Pfeifer, Ray E.; Spencer, John S., Jr. No date. The growing timber resources of Michigan: Northern Lower Peninsula. Lansing, MI: Michigan DNR. 112 p.

[2] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[3] Jakes, Pamela J. 1982. Timber resources of Michigan's Northern Lower Peninsula, 1980. Resour. Bull. NC-62. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 120 p.

[4] Norris, F. W. 1984. Timber Mart-North: Michigan. Stumpage Price Mart. 4(1): 4 p.

[5] Conversion factors: 1 cubic foot = 5.74 board feet; 1 cord = 79 cubic feet of wood.

Table 7.--Timber value 1966 and 1980

(In 1984 dollars)

Region or County	1966	1980	Percent increase
N. Lower Peninsula	$1,092,181,535	$1,593,720,516	46
Clare	40,424,070	53,408,730	32
Charlevoix	34,077,490	49,300,509	45
Cheboygan	47,437,815	64,721,001	36
Crawford	38,140,775	49,370,691	30
Roscommon	37,645,995	80,012,030	113

Table 8.--Timber value/acre of commercial forest land 1966 and 1980

(In 1984 dollars)

Region or County	1966	1980	Percent increase
N. Lower Peninsula	$156.16	$238.05	52
Clare	176.52	247.61	40
Charlevoix	210.75	355.70	69
Cheboygan	140.68	176.54	25
Crawford	125.63	180.91	44
Roscommon	139.48	321.33	133

Table 9.--Approximate equalized value of land and improvements

(In 1985 dollars)

County	1967		1985		Percent increase
	Total value	Per acre	Total value	Per acre	
Clare	$266,678,501[1]	$729.83	$277,021,007	$ 743.27	2
Charlevoix	199,507,075	752.57	386,814,575	1,459.13	94
Cheboygan	177,668,700	385.23	301,172,020	653.02	70
Crawford	71,577,911	199.21	186,424,357	518.85	160
Roscommon	155,350,823[2]	465.96	344,468,298	1,033.20	122
Roscommon--Improvements only		. . . .	154,790,952	464.28	--

[1] 1974 value

[2] 1966 value

Baumgartner, David C.; Marty, Robert J.
1988. Evaluation of resources at risk from wildland fires. Gen. Tech. Rep. NC-124. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 p.

Shows how existing information can be used to draw inferences about the distribution of values at risk from wildfire in Michigan, using example counties from the northern Lower Peninsula.

KEY WORDS: Fire damage, Michigan, value at risk.

FINDING OUT AND TELLING

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it--in short, "finding out and telling." As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

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United States Department of Agriculture

Forest Service

North Central
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General Technical
Report **NC-125**

A Guide to the TWIGS Program for the North Central United States

Cynthia L. Miner, Nancy R. Walters, and Monique L. Belli

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DISCLAIMER

TWIGS was developed at the North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service, (NCFES). The economic analysis routine was developed and added by the Department of Forest Resources, University of Minnesota (UMFR). The Forest Resources Systems Institute (FORS) provided partial funding for adding stocking guides and economic analysis enhancements.

The software is in the public domain and the recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced program with the exception of the economic subroutine which is copyrighted by UMFR and FORS.

TWIGS is provided "as is" without warranty of any kind, including but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The user assumes all responsibility for the accuracy and suitability of this program for a specific application.

In no event will NCFES nor UMFR be liable for any damages, including lost profits, lost savings or other incidental or consequential damages arising from the use or inability to use this program.

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Preface

This guide describes the FORTRAN version of the TWIGS program. FORTRAN TWIGS 3.0 was developed for use on the IBM computer and on the Data General MV 4000 and MV 8000 computers. A previous version (2.01) was written in Apple Pascal and is still available. All versions of TWIGS are based on and use growth-and-yield equations from the mainframe program STEMS.

TWIGS was developed at the North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service. The economic analysis routine was developed and added by the Department of Forest Resources, University of Minnesota. TWIGS was adapted for the Data General in cooperation with Region 9 of the USDA Forest Service. Incorporation of stocking guides and enhanced economics into TWIGS was partially funded by the Forest Resources Systems Institute, which receives Federal financial assistance.

The evolution of STEMS and TWIGS has involved many people. Primary in the research were Gary Brand, David Belcher, Roland Buchman, Burton Essex, Stephen Fairweather, Jerold Hahn, Margaret Holdaway, Tim Krohn, Rolfe Leary, Allen Lundgren, Lewis Ohmann, Stephen Shifley, and Brad Smith. Programmers who helped develop and refine the TWIGS and STEMS software include Kevin Nimerfro, Kevin Low, Michael Steinbach, and David Kowalski. Ray Ellis, Timber Management, was instrumental in "custom-fitting" TWIGS for Region 9's use. The authors provided a link between the users and researchers, coordinating distribution and refinement of the software. Essential to the refinement of TWIGS were criticism and suggestions from many individuals from various agencies, industries, and organizations.

of trees. From run menus provided by the interactive TWIGS program, the user chooses growth-simulation parameters (such as the number and length of growth cycles), values for economic analysis, actions for management, and characteristics for ingrowth.

During the growth projection, the user can manage the stand by choosing from a variety of silvicultural prescriptions. After management, a real or nominal economic analysis can be made to examine the internal rate of return, net present values, benefit/cost ratio, and other economic performance measures. The user also has the opportunity to add new trees (ingrowth) after each growth cycle. Stand reports show changes in productivity and volume after each cycle of growth and management simulation.

This paper describes the basic principles and technical aspects of the TWIGS program. For the novice TWIGS user, the guide explains how to use the program. (Users are assumed to be familiar with the hardware with which TWIGS is used.) With this guide in hand and the TWIGS program on the screen, those of you who are using the program for the first time should be able to do so without assistance. Users with previous TWIGS experience may find this guide provides new insights into the program. Detailed information about the program is in the appendices, including growth equations, coefficients, and validation tables. For further information, see the references listed in the bibliography. Source codes are available on diskette.

The following section describes the principles of TWIGS. Please look this section over before going on to the operating instructions for TREEGEN and TWIGS. You may wish to read these principles, particularly the cautions, once again carefully after first using the TWIGS program and later on for reference.

THE PRINCIPLES OF THE TWIGS PROGRAM

Forecasting Growth and Mortality

Growth and mortality equations are the core of TWIGS as a growth simulator. These equations were developed for the Lake States from measurements of 1,500 plots with 80,000 trees and for the Central States from measurements of 3,000 plots with 60,000 trees. Following is a general discussion of the equations used for the 31 species groups in TWIGS. See appendix A for a list of the species groups. Appendix B includes the mathematical model forms for growth, mortality, and crown ratio, along with the species-specific regression coefficients.

Growth Equation.—This equation annually estimates diameter growth for each sample tree and updates the crown ratio of the tree:

Annual Diameter Growth = Potential Growth × Competition Modifier

> **Potential growth** is predicted for each tree as if it were growing without competition. This growth varies by species and is calculated with tree-crown ratio, diameter at breast height (d.b.h.), and site index.
>
> **Competition modifiers** reduce the potential tree growth to reflect stand competition based on stand basal area and the size of each tree in relation to the tree of average stand diameter.

Site Index.—TWIGS requires site index as an input for the potential growth equation. With both Central and Lake States TWIGS, the user can input one stand site index or different site indices for each species in the stand. Site index conversion tables in *Lake States* TWIGS will automatically convert stand site index to species site index (Carmean 1979, 1982; Carmean and Vasilevsky 1971). In *Central States* TWIGS, no site index conversion tables exist; if a stand site index is entered, this index is applied to all species on the tree list.

Tree Mortality.—TWIGS calculates this equation by estimating the probability of death for each tree in a given year. The tree's current d.b.h. and vigor are used to estimate mortality. The TWIGS program does not incorporate catastrophic mortality, such as from fire or insect epidemics, into the equation.

Model Assumptions and Applications

To obtain the best results from TWIGS and to know the programs limits, a user should be aware of the model's assumptions. Note that most of what follows can also be found in the cautions component of TWIGS.

A Regional Model.—TWIGS and its parent mainframe model, STEMS, are regional growth projection systems. Data used to develop the Lake States variant came from Michigan, Minnesota, and Wisconsin. Most of the data used to calibrate the Central States variant came from Indiana and Missouri. A small amount of additional data, however, came from western Kentucky and Tennessee, from southeastern Ohio and from northern Illinois (fig. 2).

Because the TWIGS data came from across each region, the program reflects the average species growth and mortality for the Lake or Central States regions, not for specific localities. The equations that estimate this growth and mortality have gone through intensive validation, substantiating the quality of the estimates at a *regional* level (Holdaway and Brand 1986). When TWIGS is used to estimate growth of one stand in a specific locale within a region, the actual growth may or may not be close to the TWIGS estimate of the average tree growth. TWIGS, therefore, should be used to compare the relative differences in growth, yield, and economic effects between alternative management strategies rather than to project exact growth and yields that will occur 10, 20, or 50 years from now. If the user requires localized estimates, methods have been developed for improving TWIGS estimates for local conditions with additional diameter-growth information (Smith 1983, Holdaway 1985, Gertner 1984).

Stand Conditions and Species.—Reliable results can be obtained with TWIGS on the average; nonetheless, the data used to develop the program

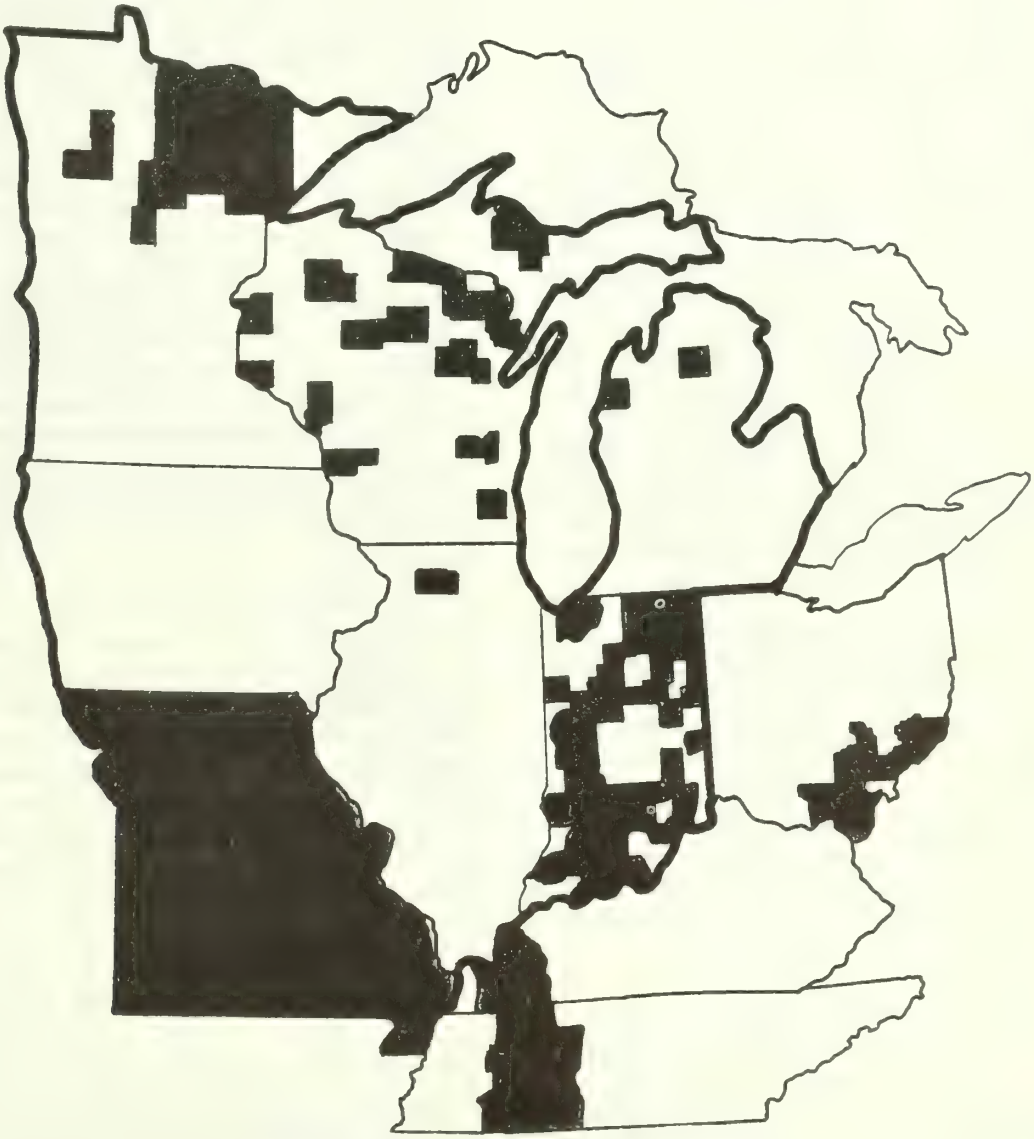


Figure 2.—*Location of data plots. Counties containing at least one plot are shaded.*

cannot reflect the complexity and variability of forest stands. Reasonable results should not be expected if the tree list used to initiate the projection does not fall within the range of conditions represented by the data that were used to develop the TWIGS projection models. To assure the best results with TWIGS:

- include at least 10 sampled trees per tree list,
- avoid projection of plantations in the Central States,
- avoid tree lists comprised predominantly of trees less than 2 inches d.b.h.,
- set the projection interval to 5 years or less, and
- limit the total projection to 30 years.

Below are stand-condition and species recommendations specific to the Central and Lakes States variants. Appendix C shows how well the species were represented by the data that were used to develop the TWIGS equations and serves as a rough guide to the reliability of equation sets for species and species groups.

Central States TWIGS was designed to estimate growth and mortality of forest-grown trees on sample plots in Missouri, Indiana, and Illinois. The data used in the development of the Central States models include:

- even-aged and uneven-aged, mixed hardwood forest stands and softwood stands of natural origin,
- site indices of 40 to 99 feet, base age 50 years (majority 65 to 75 feet),
- basal areas of 25 to 125 square feet per acre, and
- mean stand diameters between 2 and 22 inches (majority between 4 inches and 21 inches d.b.h.).

Species were not equally represented in the data base used in developing the Central States model. The species with greatest representation were the oaks, hard maple, and shortleaf pine. Eastern redcedar, yellow poplar, and tupelo/gum were poorly represented in the data base, and confidence in projections for these species is diminished accordingly. Best results are expected for species that are well represented in the data base and are growing within the range of stand and site conditions described above.

Lake States TWIGS was designed to estimate growth and mortality of forest-grown trees on sample plots in Michigan, Minnesota, and Wisconsin. More reliable results are expected from the northern portions of these states. Most of the stands used to develop Lake States TWIGS had:

- site indices of 45 to 75 feet, base age 50 years,
- basal areas of 25 to 150 square feet per acre, and
- mean stand diameters between 4 and 10 inches.

Species were not equally represented in the data base used in developing the Lake States model. Jack pine, red pine, and sugar maple were well represented; silver maple, white ash, and hickory were not. More confidence can be placed in projections of species that are well represented.

Species Groups.—To simplify reporting growth and mortality projection results, Lake States and Central States TWIGS classify trees into 31 species groups (appendix A). These species groups combine minor species with other species of the same genus or with those having similar silvical characteristics. Growth and mortality for the trees in each species group are estimated by one of 28 different equation sets in Lake States TWIGS and 22 different equation sets in Central States TWIGS. Some species groups, therefore, share the same projection equations, and trees in those groups grow and die identically.

For example, equations calibrated with shortleaf pine data in Central States TWIGS are used to estimate change for shortleaf pine trees *plus* trees in the "Virginia pine" group and the "other pines" species group. This is because insufficient data existed to fit unique equations for Virginia pine and some of the other softwoods. Projection of an occasional Virginia pine or white pine tree with the shortleaf pine equations would not make a significant difference. Central States TWIGS, however, should not be used to forecast the development of a real or hypothetical Virginia pine or white pine plantation.

"Virginia pine" and "other pines" are maintained as separate species groups in Central States TWIGS because some users expressed an interest in separating these volumes in output summaries and because equations specific to Virginia pine or other pines may be developed. The same situation exists for some other species groups that, like Virginia pine, were retained as separate groups to increase program flexibility and to make it easy to add equation sets.

Validation of Growth Equations

In the validation of *Lake States* STEMS, which also applies to TWIGS, Holdaway and Brand (1986) found that STEMS undergrows trees on the average by 0.06 inches in 10 years. On 71 percent of these trees, STEMS predicted the diameter to within 0.5 inches of the observed diameter after 10 years of growth. Likewise, the model overestimated stand basal area an average of 0.9 square feet per acre after 10 years of growth. On 72 percent of the plots examined, STEMS predicted the basal area within 10 square feet per acre of true value. See appendix D for detailed tables of predicted and observed values for diameters, basal area, and mortality. Preliminary results from the yet unpublished *Central States* STEMS evaluation are also in appendix D. An independent evaluation of TWIGS for Illinois forests is reported by Kowalski and Gertner (in prep.).

Volume Equations

In TWIGS, estimated board-foot, cord, and cubic-foot volumes are based on Upper Peninsula of Michigan equations for Lake States TWIGS (Raile *et al.* 1982) and Indiana equations for Central States TWIGS (Smith and Weist 1982). Volume equations and coefficients are in appendix E. Both sets of volume equations were developed from measurements of d.b.h., merchantable height, top diameter outside bark (top d.o.b.), site index, and tree class. Trees can fall into any of three condition classes (Doman *et al.* 1981):

- acceptable (code 20),
- undesirable (code 30), and
- cull (code 40).

The product class limits as set by the volume equations are pictured in figure 3 where:

Saw-log volume includes acceptable trees with a d.b.h. equal to or greater than 9 inches (softwood) or with a d.b.h. equal to or greater than 11 inches (hardwood). Minimum top saw-log diameters are 7 inches (softwood) or 9 inches (hardwood).

Pulpwood volume includes acceptable and undesirable trees with a d.b.h. equal to or greater than 5 inches (excluding the saw-log portion of acceptable sawtimber size trees, which is tallied under saw-log volume). Minimum top d.o.b. is 4 inches. One cord equals 79 cubic feet.

Total merchantable volume is the sum of the saw-log and pulpwood volume.

Residue includes volume in tops (less than 4 inches d.o.b. to a 1-inch d.o.b.), limbs, trees less than 5 inches d.b.h., and cull trees.

OPERATING THE TREEGEN PROGRAM

TREEGEN is a computer program, separate from TWIGS, that puts stand and tree information into a format that TWIGS can read (appendix F). TREEGEN creates tree lists for both Lake States and Central States TWIGS using lists of species names and codes. Because you will use TREEGEN to create a tree list before using TWIGS, the TREEGEN operating instructions are presented next. When running TWIGS, you will retrieve the tree list file created by TREEGEN.

This section begins with introductory information about TREEGEN, which is later explained in detail. Please read the entire section before you begin TREEGEN. One thing to keep in mind if you

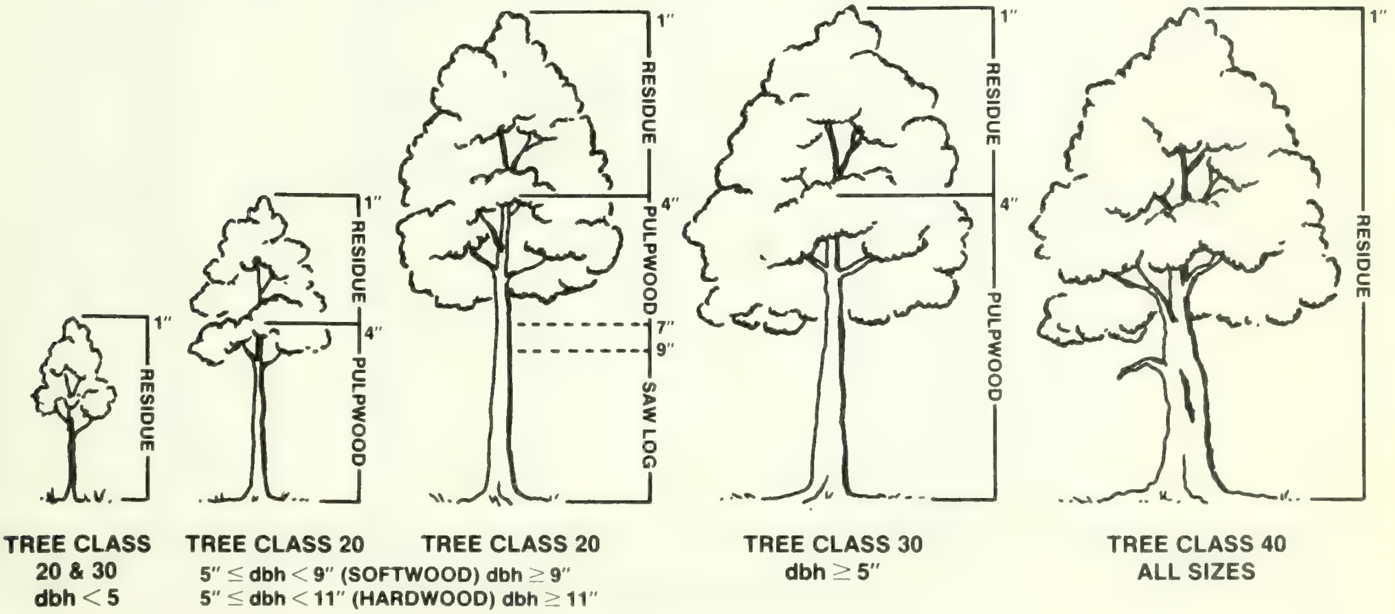


Figure 3.—*Product class limits used in TWIGS.*

use an option to print: be sure your printer is on; otherwise, the program may not function.

TWIGS was designed to use individual tree information from actual plots. For example, data taken from Forest Service plot cards, such as card code 8 from the silvexam tally sheet, can be used. Reliable, actual individual tree information will give the most accurate projection. Sometimes detailed information, however, may not be available or necessary for a TWIGS projection. In these instances, TREEGEN can create a tree list with stand level data and parameters that indicate the general shape of the diameter distribution of the stand. The user can choose from either a normal or Weibull diameter distribution to create a tree list that most closely approximates the desired stand. Whether the user enters the information with the individual tree entry or either of the two stand-level entry methods, the resultant tree lists are on a per acre basis and are in the identical format (fig. 4). Also for each method, a maximum of 500 trees can be entered into a list.

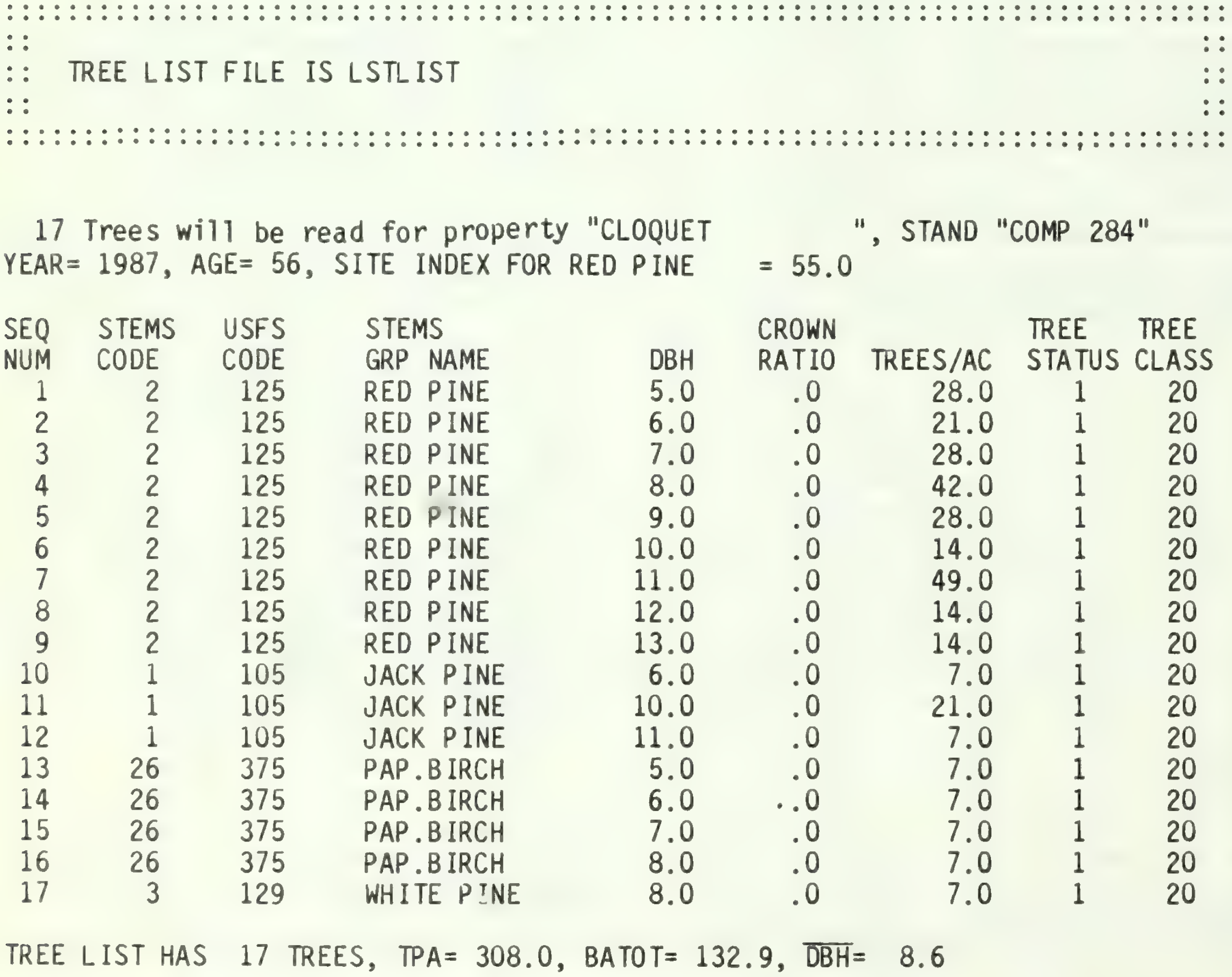
First, TREEGEN displays its inputs and outputs (these will be explained later in this section). Second, the program gives you options to select whether or not the list of species names and codes is to be shown on the screen, printed, or both. The species codes will be needed to enter trees; a printout, therefore, is convenient to have for reference. These codes are also provided in appendix A.

The third step in TREEGEN is to provide the following information:

- property name (up to 16 characters),
- stand name (up to 8 characters),
- year of measurement, and
- age at year of measurement (in an uneven-aged stand, use the age of the component of the stand that will most likely be managed).

After entering the above data, you are given the opportunity to change the values before going on to the following item:

- Stand site index. Enter the Forest Service species code (appendix A) and then the site index for that



```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                        ::
::  TREE LIST FILE IS LSTLIST                                             ::
::                                                                        ::
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::;::::::::::


  17 Trees will be read for property "CLOQUET          ", STAND "COMP 284"
YEAR= 1987, AGE= 56, SITE INDEX FOR RED PINE    = 55.0

SEQ   STEMS   USFS     STEMS                      CROWN              TREE   TREE
NUM   CODE    CODE     GRP NAME           DBH     RATIO   TREES/AC   STATUS CLASS
  1      2     125     RED PINE           5.0      .0        28.0      1      20
  2      2     125     RED PINE           6.0      .0        21.0      1      20
  3      2     125     RED PINE           7.0      .0        28.0      1      20
  4      2     125     RED PINE           8.0      .0        42.0      1      20
  5      2     125     RED PINE           9.0      .0        28.0      1      20
  6      2     125     RED PINE          10.0      .0        14.0      1      20
  7      2     125     RED PINE          11.0      .0        49.0      1      20
  8      2     125     RED PINE          12.0      .0        14.0      1      20
  9      2     125     RED PINE          13.0      .0        14.0      1      20
 10      1     105     JACK PINE          6.0      .0         7.0      1      20
 11      1     105     JACK PINE         10.0      .0        21.0      1      20
 12      1     105     JACK PINE         11.0      .0         7.0      1      20
 13     26     375     PAP.BIRCH          5.0      .0         7.0      1      20
 14     26     375     PAP.BIRCH          6.0     ..0         7.0      1      20
 15     26     375     PAP.BIRCH          7.0      .0         7.0      1      20
 16     26     375     PAP.BIRCH          8.0      .0         7.0      1      20
 17      3     129     WHITE PINE         8.0      .0         7.0      1      20

TREE LIST HAS  17 TREES, TPA= 308.0, BATOT= 132.9, DBH=  8.6
```

Figure 4.—*Tree list.*

species. In both Lake and Central States TWIGS, you can also enter *species-specific* site indices. Lakes States TWIGS, however, includes tables that will convert a *stand* site index to species-specific site indices if species-specific site indices are unavailable. Central States TWIGS does not have site-index conversion tables. If available for Lake or Central States, enter the actual species-specific site indices into TREEGEN. Actual data will always be more reliable than the data the TWIGS program would generate with conversion tables.

You will be given an opportunity to change the site index for each species. Once a species has been entered, however, the species cannot be deleted.

The fourth step in TREEGEN is to select the method you will use to create a tree list from the following:

- normal distribution,
- Weibull distribution, and
- individual tree.

Normal Distribution

This option is used for cases in which individual tree information is not available and generally for even-aged stands. A normal distribution typifies a bell-shaped "normal curve" with most of the trees centered around the mean diameter class (fig. 5).

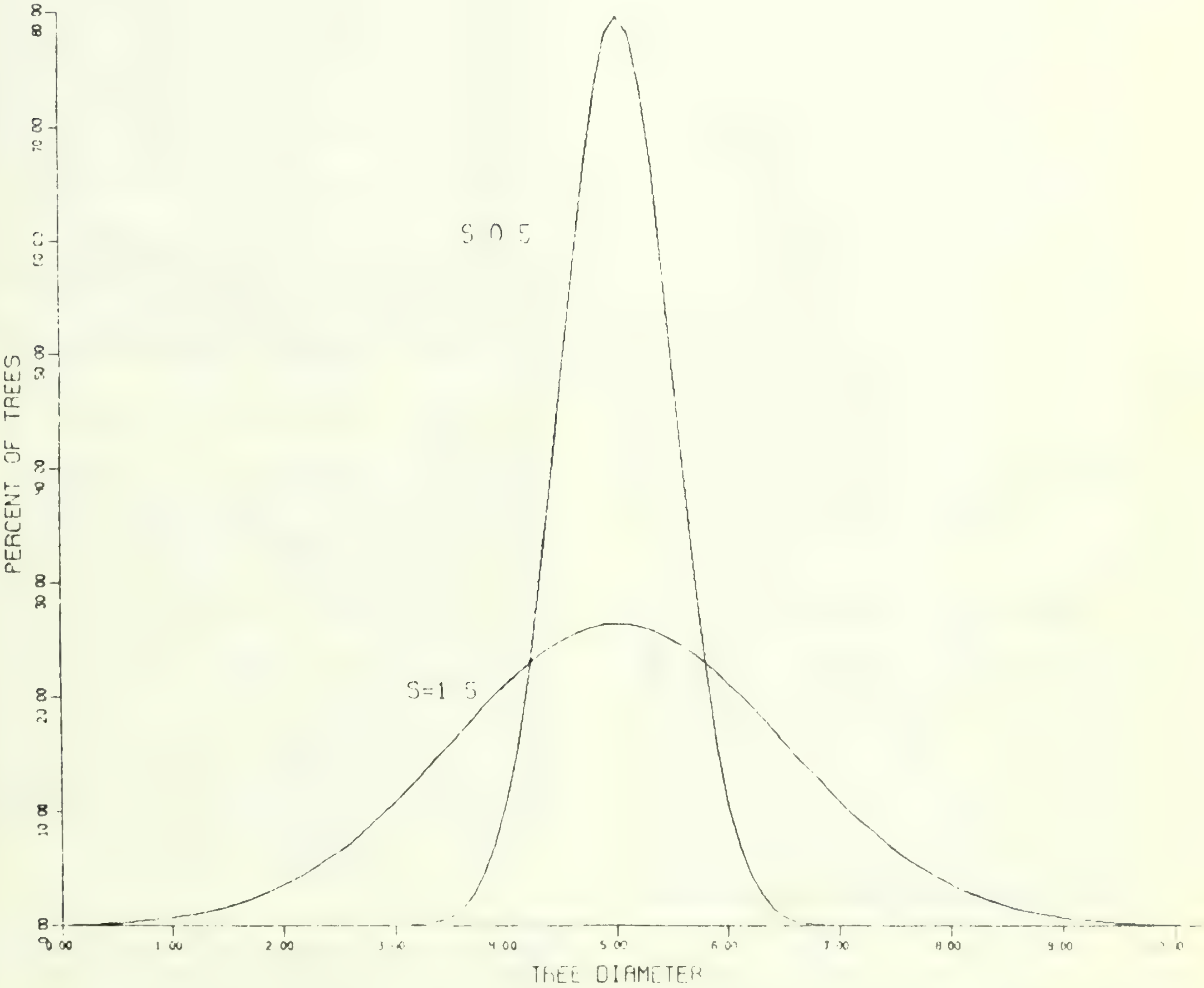


Figure 5.—*Normal distribution with two different standard deviations (s = standard deviation).*

Any number of species groups, each with a different normal diameter distribution, can be included in the tree list.

For the normal distribution option, you provide the following:

- Forest Service species code (appendix A),
- number of trees per acre represented by this species group, from 0.1 to 4,000 trees,
- average d.b.h. (1.0 inch-30.0 inches), and
- standard deviation. TREEGEN automatically defines the limits of the standard deviation so that it cannot be larger than

  [Average d.b.h.] /3.

  If the standard deviation is small, most of the trees will center about the mean diameter and a high and narrow bell-shaped curve results. Conversely, a large standard deviation indicates fewer trees are close to the mean diameter and a broad curve results (fig. 5).

  When you have completed an entry for a species and wish to add another entry, press "0" to accept the completed entry. You will then be shown a list of the new trees that have been added and will be given the opportunity to add another species group entry.

When finished with all normal distribution entries, press "Z." The tree list and a summary can then be printed, displayed, or both. If you wish to make changes, display or print the tree list so that you can identify the trees to be changed. The last step in TREEGEN is to type a file name for the tree list. You will use this file name while operating TWIGS.

Weibull Distribution

This option is for when individual tree information is not available and when the stand being created is even- or uneven-aged. The Weibull distribution produces a wide range of diameter distribution shapes. One shape is the reversed J-shaped curve of a balanced, uneven-aged stand, often having two or more age classes occupying an equal area (fig. 6a). Another shape is the humped-curve of an irregular uneven-aged stand that does not include all age classes; this curve often represents an unmanaged or high-graded stand (fig. 6b).

You provide the following information for each species group:

- Forest Service species code (appendix A).
- Number of trees per acre represented by this species group from 0.1 to 4,000 trees.
- *A Parameter* (valid entries are 0-29.9 inches). This is the location parameter that specifies the diameter of the smallest tree on the tree list. Changing this location parameter shifts, on a graph, the diameter distribution to the right or left of the original diameter axis (compare fig. 6c and 6d). Setting A = 1 is usually appropriate for young stands and even-aged stands.
- *B Parameter* (valid entries are > 0). Also called the scale parameter, this corresponds to the diameter of a tree at the 63rd percentile of the diameter distribution. In other words, 63 percent of the trees on the tree list will have diameters smaller than the sum of the parameters A and B. Conversely, 37 percent of the trees on the list will have diameters larger than the sum of parameters A + B. For given A and C parameters, higher values of B correspond to a flatter diameter distribution.
- *C Parameter.* As the shape parameter, this parameter defines the general shape of the diameter distribution. Specifically:

  $C < 1$ creates a reversed J-shape distribution (fig. 6a),

  $C = 1$ creates an exponential distribution (fig. 6e), and

  $C > 1$ creates a distribution with a single peak or hump (fig. 6b).

  The shape of the hump changes with the value of C, as follows:

  $1 < C < 3.6$ creates a long tail on the right (fig. 6b),

  $C = 3.6$ approximates a normal distribution (figs. 6c and 6d), and

  $C > 3.6$ creates a long tail on the left (fig. 6f).

  For information on how to estimate parameters B and C from the mean and standard deviation of the stand, see Shifley and Lentz (1986).

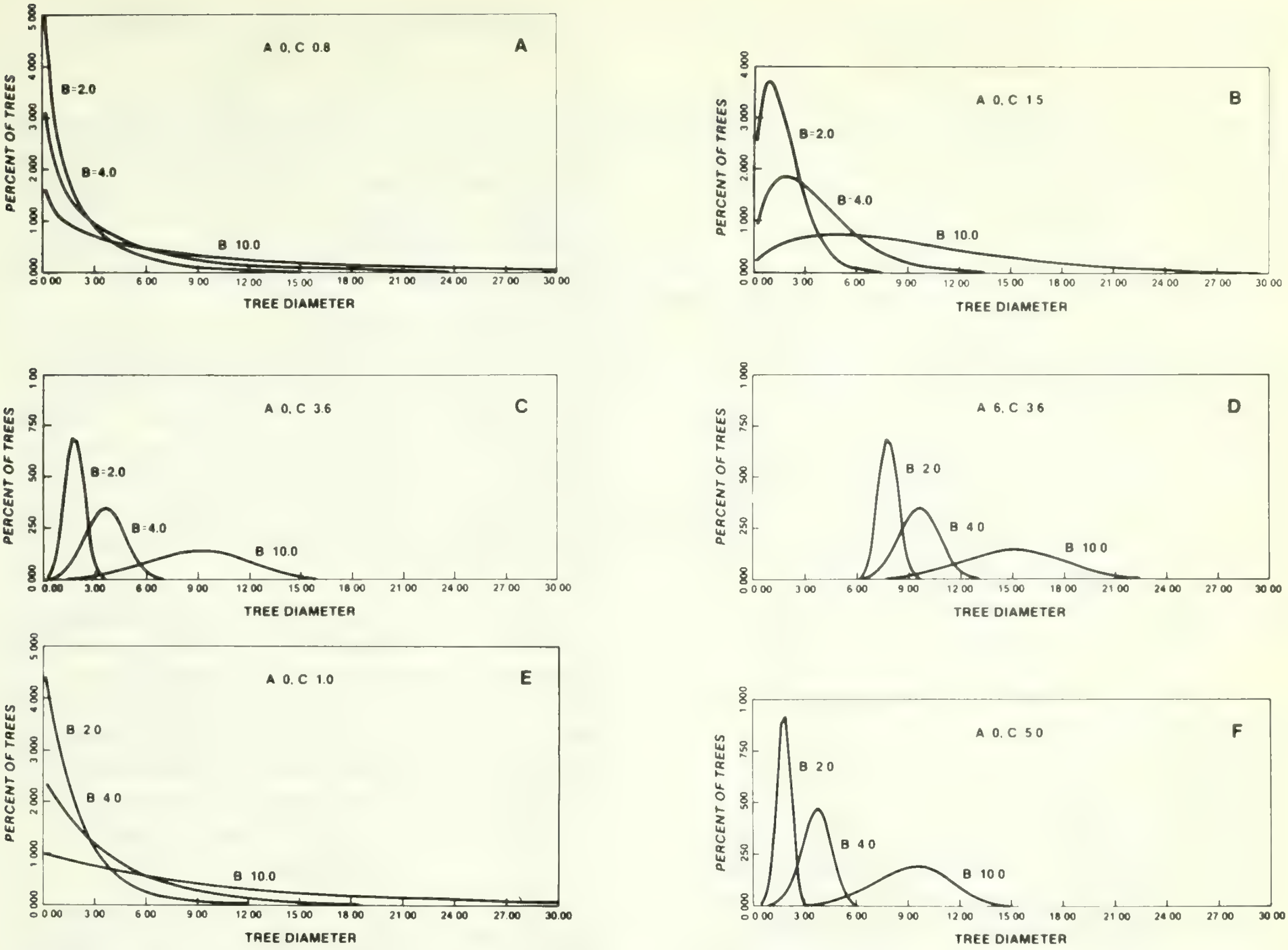


Figure 6.—*Weibull distribution: a. Reversed J shape; C < 1. b. Hump shape; C > 1. c. Low A parameter; C = 3.6. d. High A parameter; C=3.6. e. Exponential; C=1. f. With long tail on left; C > 3.6.*

When you have completed an entry for a species and wish to add another entry, press "0" to accept the completed entry. You will then be shown a list of the new trees that have been added and be given the opportunity to add another species group entry.

When finished with all entries, press "Z." At this point, if you wish to make changes, display or print the tree list so that you can identify the trees to be changed. The last step in TREEGEN is to type a file name for the tree list. You will use this file name while operating TWIGS.

Individual Tree

With this tree list entry option, you can create a tree list directly from a sample of individual trees in a stand. The sample can be from any size plot (variable or fixed-radius) and can represent one plot or a combination of plots. Forest Service silvexam stand tally sheet R9-2400-14 provides the necessary information for building a tree list.

Expansion Factor.—The tree expansion factor puts the sample trees on a per acre basis. The factor varies by the type and size of the plot and the number of plots being combined into one tree list. For instance, the tree expansion factor for a variable-radius plot varies with the size of the sample tree and is calculated with the following equation:

Tree expansion factor = $BAF/(0.005454D^2\ n)$;

where BAF = basal area factor of the prism or single gauge,
n = the number of sample plots, and
D = diameter at breast height.

The user can supply the expansion factor or let TREEGEN calculate it. One of these options must be selected before any expansion factors are entered.

If TREEGEN is used to calculate the expansion factor, the user provides the BAF and n.

Calculating the expansion factor for a fixed plot is easier than for a variable-radius plot. For example, one sample tree on a tenth-acre fixed plot would represent 10 trees per acre. If five tenth-acre plots were being combined into one tree list, each tree would represent two trees per acre.

The expansion factor can minimize the amount of data entry. If more than one sample tree on the plot has the same characteristics (such as species, d.b.h., crown ratio, status, and tree class), those trees can be represented by one tree list entry. The expansion factor for that entry is multiplied by the number of sample trees being aggregated. For instance, if 12 live red pine trees are on a tenth-acre plot with a d.b.h. of 6 inches, tree class 20, and no crown ratio measured, only one of those 12 trees need be entered. The expansion factor for that one entry would be 120 (12 trees × 10 trees per acre).

Sample Trees.—The information required for each sample tree is:

- Forest Service species code (see appendix A),
- tree d.b.h. (1.0-30.0 inches),
- crown ratio code (0.0-9.9; 0.0 = not measured). An optional variable, the crown ratio is defined as the percent of the total height of the tree in live crown. The codes 1, 2,..., 9 represent crown ratios of 1-10 percent, 11-20 percent,..., 81-100 percent, respectively. If 0.0 is entered, TWIGS automatically calculates the crown ratio. See appendix B for the crown ratio equation and coefficients.
- Expansion factor (number of trees per acre from 0.1 to 4,000 trees).
- Tree status (1=live, 2=cut, 3=dead).
- Tree class (20=acceptable, 30=undesirable, 40=cull).

After you provide the above characteristics, indicate how many sample trees have these characteristics. To expedite this process, constants can be assigned. When the tree list is complete, the stand summary can be printed or displayed. At this point, you may make changes. The last step in TREEGEN is to type a file name for the tree list. You will use this file name when you operate TWIGS.

OPERATING THE TWIGS PROGRAM

We advise first-time TWIGS users to read all of the instructions for TWIGS before beginning to run the program. Before you begin, have ready a computer file that contains a list of trees representing the stand to be projected. This file can be generated with TREEGEN, as previously described.

The TWIGS components are described in the order in which they appear in the program. As the components are discussed, 14 basic steps used to operate TWIGS are explained. In these steps, you select parameters and values that characterize the projection of a stand. Appendix G shows an example projection for the 30-year-old red pine stand that is on the distribution disk for Lake States TWIGS (file name LSTLIST).

Note that you will only be able to move forward in TWIGS. To exit the program, move forward until you get to the run options where you select option "J" to end TWIGS. As in TREEGEN, be sure that the printer is on if you select the printing option, or TWIGS may not function. Also note, all input and output are on a per acre basis.

Cautions

After displaying a software disclaimer, the TWIGS program gives you an opportunity to see the cautions described in this guide's section on forecasting growth and mortality.

Step 1
Indicate if you want to see a list of cautions for applying TWIGS: Y = yes and N = no.

Run Options

TWIGS uses a menu of run options to characterize the projection (fig. 7). In the run options, the number of growth cycles, the length of each growth cycle, and other run characteristics are determined. These options can be changed at the beginning and periodically throughout the program run. Each option has a default value that is used unless the user changes it. Once a run option is changed, the new value is used as the default for subsequent TWIGS runs.

```
===========================================================================
   R U N   O P T I O N S

OPTION   VALUE   DESCRIPTION
===========================================================================
  A        1     Years in projection interval
  B       10     Years in growth cycle
  C        2     Number of cycles
  D        1     Management: 0=off, 1=on
  E        1     Economic evaluation: 0=off, 1=on
  F        0     Message level: 0=normal,other=debug
  G        1     0=Only screen is used, 1=printer is used
  H        2     0=No volumes, 1=Volumes in INT. 1/4", 2=Volumes in SCRIBNER
  I        1     Diameter classes:
                   0=No diameter class breakouts
                   1=Three classes: 0-4.9, 5.0-10.9, 11.0+
                   2=Five classes: 0-2.9, 3.0-4.9, 5.0-10.9, 11.0-16.9, 17.0+
                   3=User-specified diameter classes
  J        0     1=Immediately end the program
```

Figure 7. *Menu of Run Options.*

Step 2
Run Options. Select the options that will characterize the projection to be made. When you are finished, press "Z."

Following is a description of the run options. Note that if you want to end the program immediately, change option "J" from 0 to 1. Additionally, option "G" indicates if a printer is to be used. If option "G" has the value of 1 and the printer is not on line, the program will not run.

Option A. YEARS IN PROJECTION INTERVAL is the frequency at which the growth and mortality equations will be applied. For example, with a projection interval of 1 year, the equations are applied annually. With a projection interval of 5 years, the equations are applied every 5 years and the average annual growth and mortality over that 5-year period are used.

Because of the effect of averaging, more years in a projection interval mean less accurate growth predictions. IBM-PC and Apple users will notice that more years in a projection interval also mean faster TWIGS calculations; for some TWIGS users, therefore, a trade-off exists between accuracy and speed. In any case, we suggest that the projection interval not be set over 5 years; higher intervals substantially reduce the quality of the projections (see the validation section).

Option B. YEARS IN GROWTH CYCLE determines how often you will receive a stand and stock report during the projection and have the opportunity to manage the stand. For example, a 10-year growth cycle means that a stand report is presented at the end of every 10 years; at this point, you have the options to manage the stand, see an economic analysis, and add ingrowth. During this 10-year period, growth and mortality equations will be applied as often as specified for YEARS IN PROJECTION INTERVAL (option A). If option A was set to 5 years, then equations will be applied twice in a 10-year growth cycle. Note that the YEARS IN GROWTH CYCLE must be a multiple of YEARS IN PROJECTION INTERVAL.

Option C. NUMBER OF CYCLES determines how many growth cycles there will be during a TWIGS run. For example, three growth cycles of 10 years each will give a projection period of 30 years. Moreover, if the user chooses a PROJECTION INTERVAL of 5 years, then the growth and mortality equations will be applied six times during that 30-year period.

Option D. If the MANAGEMENT option is turned on, you have the opportunity to manage the stand during each growth cycle. If this option is turned off, you will have no opportunity to manage the stand before the first growth cycle. This and other options, however, can be changed periodically throughout the run.

Option E. The ECONOMIC EVALUATION option can be turned off if an economic evaluation is not needed.

Option F. The MESSAGE LEVEL can be used by a programmer to debug TWIGS.

Option G. The PRINTER option allows TWIGS to be used without a printer.

Option H. The VOLUME option determines if volumes will be calculated, and whether in International ¼ inch rule, Doyle rule (Central States), or Scribner Decimal C rule (Lake States).

Option I. DIAMETER CLASSES creates diameter-class limits for stand reports. These same limits can also be used for diameter-class thinning when simulating management.

Option J. The TERMINATION option, when changed from **0** to **1**, ends the program immediately.

Tree List

The tree list is usually generated with the TREEGEN program, described earlier. If the tree list is on file, you access the file for TWIGS by the following steps.

Step 3
Species Names and Codes. Press "Y" if you want to see a list of species names and codes. You also have the option to print the list. The printed list is convenient for later reference, particularly if you want to add trees later with the ingrowth component. The species list is also shown in appendix A.

Step 4
Tree List File Name. Type the tree list file name to enter it into the projection, or press "D" to see a directory of files from which to choose a tree list file.

Step 5
Tree List Presentation. Choose to see the tree list or move directly to the next component of TWIGS. If in the run options you decided not to use the economics component, go to page 20. If you chose to do an economics evaluation, go to the following Economics section.

Economics

The TWIGS economic component is designed to help evaluate the economic performance of project alternatives. The user should understand the conceptual basis of financial analysis and the data inputs required for applying the results. Background information on financial analysis concepts and applications and forestry project analysis can be found in: Guide to Forestry Investment Analysis (Rose *et al.*, 1988). An example of conducting an investment analysis with TWIGS is in Blinn *et al.* (in prep.).

TWIGS can be used to organize and develop a cash-flow table and to set stumpage rates for various products and species. All cash flows are entered in base-year dollars on a per acre basis as positive values and are assumed to take place at the *beginning* of the year of occurrence.

TWIGS Economic Analysis Inputs.—Before you select options from the Economics Menu, the initial stumpage rate default values are displayed (fig. 8). The Economics Menu (fig. 9) is then shown with the economic parameters that are to be defined. This is where the stumpage-rate default values can be changed.

Step 6
Economics Options. Select the economics options (fig. 9) for characterizing your economic evaluation. Program default values have been set for appropriate options. If not changed, these default values are used for the economic analysis. Once changed, the option value is retained and becomes the new default value for subsequent TWIGS runs. Type "Z" when you are finished selecting options, which are described next.

Options A, B, and C set sawtimber, poletimber, and residue stumpage prices. The default values apply to all species, unless otherwise indicated in Option D. New stumpage rates for all species may be entered by selecting the appropriate option. Product class limits are shown in figure 3.

Option D sets individual sawtimber, poletimber, and residue stumpage rates for up to 10 species. To change individual species-product stumpage rates, enter the appropriate three-digit Forest Service species code (appendix A), select the products to be altered, and enter the new stumpage rate. Individual stumpage rates set in this option are *not* retained for subsequent TWIGS runs.

Option E sets the annual real stumpage price inflation rate. The default value is 0 (zero) percent.

```
DEFAULT STUMPAGE RATES:

        SAWTIMBER      POLETIMBER     RESIDUE
        $/1000 BDFT    $/CORD         $/100 CUFT
        -----------    -----------    -----------
        $      29.00   $      6.00    $       .00
```

Figure 8. *Initial stumpage-rate default values as defined by TWIGS.*

```
ECONOMICS MENU:

OPTION  VALUE  DESCRIPTION
  A   $ 29.00  Stumpage rate per 1000 board feet of sawtimber (default value).
  B   $  6.00  Stumpage rate per cord of poletimber (default value).
  C   $   .00  Stumpage rate per 100 cuft of residue (default value).
  D            Change stumpage rates for a species ( 0 set, 10 available).
  E         0  Annual stumpage price inflation rate (in percent).
  F         1  Set option to print cash flow table
               0 = Do not display table
               1 = Display table
  G      1987  Base year for economic analysis (less than or equal to 1987).
  H      5.00  Real discount rate (in percent).
  I            See, add or edit the diary of cost and revenue activities (per
               acre).
  J         0  Set option to discount the cash flows.
               0 = Discount all cash flows through 2007.
               1 = Do not consider cash flows beyond the
                   current projection year (1987).
  K            Show economic evaluation on screen.
  L            Show economic evaluation on screen & printer.

  Type option letter or type  Z  to continue:
```

Figure 9.—*Economics Menu with default values.*

With this option, you can enter a real rate of increase in stumpage rates, based upon historical data or other information. The value entered is applied to all species-product stumpage prices incorporated in the analysis.

Option F gives you the opportunity to suppress or print the cash-flow tables. The individual cash-flow table is displayed 5 years at a time.

Option G sets the base year to which all cash flows are discounted in the economic analyses. This option must be set to a year that is less than or equal to the current year of the projection. The default value is the measurement year from the tree list data file. The base year may be changed to a year previous to the measurement year to allow past costs and revenues to be considered. *If you plan to input past activities, change the base year (Option G) before entering these individual activities (Option I).* For any activity, a year of occurrence previous to the base year is not accepted by the program. If the Soil Expectation Value criterion is to be used when comparing investment alternatives, the base year should be set to the year of planting.

Option H, when selected, allows you to choose the type of economic analysis and the rate for discounting all cash flows. TWIGS will perform either a *real* or a *nominal* analysis, depending upon whether or not the user chooses to incorporate a general inflation rate into the analysis. A real analysis assumes that all input values are in real terms, net of inflation. A nominal analysis combines a real discount rate with a general inflation rate. Further information on determining an appropriate discount rate may be found in Rose *et al.* (in prep.). All cash flows are discounted to the beginning of the base year when a TWIGS economic analysis is calculated.

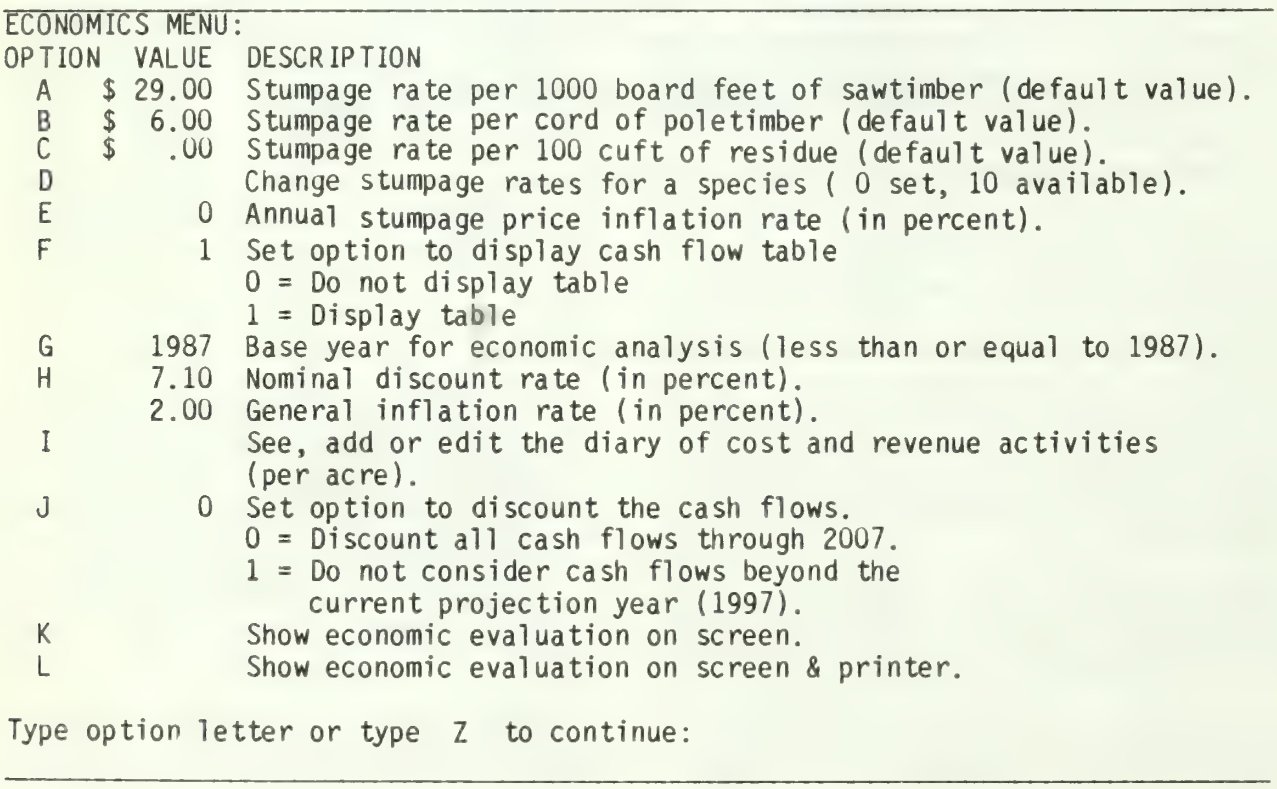
> *Real analysis* requires the real discount rate (0.01 to 100 percent)
>
> *Nominal analysis* requires the nominal discount rate followed by a general inflation rate. TWIGS automatically calculates the assumed real rate (fig. 10, option H).

Option I displays the diary of cost and revenue activities, allowing addition or editing of the activities. All cash flows should be entered on a per acre basis in the year in which they occur. A maximum of 40 total cash-flow activities (including sale incomes described below) may be entered in the cash-flow diary for any analysis. All cash flows are assumed to occur at the beginning of the indicated year. Cost and revenues from this diary are *not* retained for subsequent TWIGS runs.

Whenever the user prescribes TWIGS management treatments that result in timber removal, a cash-flow entry entitled "sale income" is automatically entered into the cash-flow diary. This entry displays the actual cash flow that occurred and the appropriate stumpage inflation rate (option E). In the management portion of TWIGS, harvested trees may be uncut. If the trees are uncut in management, the revenue generated by the timber harvest will be automatically removed from the diary.

Note that sale-income diary entries are calculated with stumpage prices that are set before the management treatment is applied. If stumpage prices are changed after management and you want the previously calculated sale income(s) to reflect the new stumpage prices, you must hand calculate and edit the sale income diary entry(s).

If no cash-flow activities have been entered into the diary, you may type either "1" to enter the first activity or "0" to return to the economics menu (fig. 11). After entering an activity, the current state of the diary is shown with the options to either edit an existing activity, add a new activity, or return to the economics menu (fig. 12). To *edit* an activity,



```
ECONOMICS MENU:
OPTION  VALUE  DESCRIPTION
  A    $ 29.00  Stumpage rate per 1000 board feet of sawtimber (default value).
  B    $  6.00  Stumpage rate per cord of poletimber (default value).
  C    $   .00  Stumpage rate per 100 cuft of residue (default value).
  D             Change stumpage rates for a species ( 0 set, 10 available).
  E           0 Annual stumpage price inflation rate (in percent).
  F           1 Set option to display cash flow table
                0 = Do not display table
                1 = Display table
  G        1987 Base year for economic analysis (less than or equal to 1987).
  H        7.10 Nominal discount rate (in percent).
           2.00 General inflation rate (in percent).
  I             See, add or edit the diary of cost and revenue activities
                (per acre).
  J           0 Set option to discount the cash flows.
                0 = Discount all cash flows through 2007.
                1 = Do not consider cash flows beyond the
                    current projection year (1997).
  K             Show economic evaluation on screen.
  L             Show economic evaluation on screen & printer.

 Type option letter or type  Z  to continue:
```

Figure 10.—*Economics menu reflecting a 7.1-nominal discount rate and a 2-percent general inflation rate, as set under option H.*

```
THERE ARE NOT COST OR REVENUE ACTIVITIES SPECIFIED YET.

Type 1 and press <ENTER> to add a new activity, or
Type 0 and press <ENTER> to continue:
```

Figure 11.—*Initial menu for adding the first cost or revenue activity.*

```
DIARY OF COST AND REVENUE ACTIVITIES:

      (ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY       NAME        YEAR(S)      COST     REVENUE   INFLATION RATE
-----  ------------  ----------   --------  ---------  -------------
  1    ADMIN. COSTS  1987-1997      21.73       .00          .00
  2    INVENTORY        1987        75.00       .00          .00

Type the number of the activity to be edited and press <ENTER> or Type 3
and press <ENTER> to add a new activity, or
Type 0 and press <ENTER> to continue:
```

Figure 12.—*Menu for editing or adding activities after two activities have been entered.*

you must enter the sequential number of the activity when the diary is shown. All information for that activity must be reentered.

To *add* an activity, enter the next sequential number indicated by the program. Cost and revenue activities will be automatically ordered so that all costs will be printed in the diary before any revenues, regardless of the order in which they are entered. All cash flows are entered per acre in base-year dollars.

For each activity, you are asked to enter the following information:

- Type of activity: 1=cost and 2=revenue.
- Descriptive name up to 12 characters in length.
- Additional interest rate above or below the general inflation rate (if appropriate). This allows you to inflate or deflate activities that historically change at a different rate than the general inflation rate. For example, in a real analysis where the general inflation rate is implied to be 0 (zero) and the desired activity inflation rate is 1.5 percent, enter 1.5 for the additional interest rate. For a nominal analysis, if the general inflation rate is 2 percent and the desired activity inflation rate is 1.5 percent, enter −0.5 for the additional interest rate.
- Type of occurrence: 1=single, 2=annual, and 3=periodic. All activities and their associated cash flows are assumed to take place at the beginning of the specified year of occurrence.

Single Occurrence is an activity that occurs once during the projection, such as land cost. You provide the *year of occurrence* (greater than or equal to the current base year and less than or equal to the last year of the projection) and the per acre *cash flow* in base-year dollars.

Annual Occurrence is an activity that occurs in each year for 2 or more consecutive years with the same cash flow occurring every year, such as property taxes. You provide the *year the activity first occurs* (greater than or equal to the base year and less than the last year of the projection), the *year the activity last occurs* (greater than the beginning year and less than or equal to the last year of the projection), and the per acre *cash flow* in today's dollars.

Periodic Occurrence is an activity that occurs more than once but not in consecutive years or that occurs in consecutive years with varying cash flows, such as sale administration. You provide the *number of times the activity occurs* and the appropriate per acre *cash flow* for each year of occurrence. *Years of occurrence* may be entered in any order and will be reordered sequentially by the program.

A periodic activity may occur every year for the length of the projection. Because activities are assumed to occur at the beginning of each year, multiple occurrences for an activity in the same year are not allowed. After each activity is entered, TWIGS checks for multiple occurrences so that the user can correct the entry before returning to the economics menu.

Option J specifies if future cash flows are to be discounted. Zero ("0") is entered to consider all cash flows through the end of the projection. All past, present, and future cash flows, therefore, can be incorporated into the analysis. One ("1") is entered when cash flows are to be considered only through the current projection year; thus, the user needs to only consider past and present cash flows. For instance, you might enter a "1" for option J if you are considering clearcutting the stand at the current projection age and want to only evaluate cash flows that could have occurred before and at the time of liquidation. If the current year is equal to the base year, option J is automatically set to "0" (zero).

Option K requests an economic analysis and indicates that output reports will be shown only on the screen.

Option L also requests an economic analysis but indicates that the output reports will be simultaneously shown on the screen and the printer. If the printer was set to off when the initial run options were set, the analysis will still be printed when this option is chosen. Be sure to turn the printer on if you select the print option.

Outputs from the Economic Analysis.— Following is a description of the economic analysis output. Appendix G shows examples of this output in which a real analysis with a discount rate of 5 percent was selected with the base year in 1987. The stumpage price inflation rate was set at 1.2 percent.

The *summary of economic analysis inputs table* (fig. 13) summarizes the input values from sale of timber and entries from option I. The two sale incomes were calculated and entered in this table by TWIGS after management treatments were prescribed.

The *annual cash-flow table* (fig. 14) contains the data necessary to calculate the various measures of investment performance. The table is primarily a listing of the cash-flow amounts for each year of the project, incorporating inflation where appropriate. The cash-flow tables also present total expenditures and receipts and net revenues for each year in the analysis.

The table for the *profile of net present values* (fig. 15) for the investment at various discount rates allows the user to assess the effect of different discount rates used in the analysis on net present value. For a nominal analysis, the table includes columns for both real and nominal discount rates.

The measures of *project performance* (fig. 16) are calculated at the user-supplied discount rate. These investment performance measures include: (1) net present value (NPV), (2) equivalent annual income (EAI), (3) soil expectation value (SEV), (4) benefit/cost ratio, (5) payback period, and (6) real internal rate of return. If a nominal analysis is chosen, the nominal internal rate of return is also listed. Definitions and interpretations of these measures of performance can be found in Rose *et al.* (in prep.).

The *sensitivity analysis* table (fig. 17) shows the sensitivity of the performance measures NPV, EAI, and SEV to a 10-percent change in the input values. Increases in costs or decreases in revenues will decrease NPV, EAI, and SEV by the amounts indicated in the table. Conversely, decreases in costs or increases in revenues will increase the performance measures. The larger the amount indicated in the table, the greater the impact of a change in the initial cash flow.

The amount of change in NPV, EAI, and SEV resulting from something other than a 10-percent change in input cash flow values can be calculated directly from the sensitivity analysis table. For example, a 20-percent change would double the values in the table; a 30-percent change would triple them; and a 5-percent change would halve them.

The *risk analysis* table (fig. 18) shows the percent change, up to 100 percent, required for each input cash-flow value to force NPV to exactly $0.00 (zero). When the percent change equals 100 percent and the dollar change is less than the calculated NPV, the input variable will not alone alter the overall project enough to make NPV $0.00 (zero).

```
                         ANNUAL CASH FLOW PATTERN

 (ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

                                                   YEAR
        ITEM           1992        1993        1994        1995        1996
===============================================================================
     Buy Land           .00         .00         .00         .00         .00
     Property Tax      1.09        1.14        1.18        1.23        1.28
     Sale Prep.         .00         .00         .00         .00         .00
     Sale Admin.        .00         .00         .00         .00         .00
-------------------------------------------------------------------------------
     TOT ANN COST      1.09        1.14        1.18        1.23        1.28
     CUM TOT COST    392.97      394.11      395.29      396.52      397.81
===============================================================================
     Sell Land          .00         .00         .00         .00         .00
     SALE INCOME        .00         .00         .00         .00         .00
     SALE INCOME        .00         .00         .00         .00         .00
-------------------------------------------------------------------------------
     TOT ANN RECP       .00         .00         .00         .00         .00
     CUM TOT RECP     82.95       82.95       82.95       82.95       82.95
===============================================================================
     ANN NET REV      -1.09       -1.14       -1.18       -1.23       -1.28
     CUM NET REV    -310.02     -311.16     -312.34     -313.57     -314.85
```

Figure 13.—*Summary of the economic analysis input values.*

```
                         ECONOMIC ANALYSIS INPUTS

       NOMINAL DISCOUNT RATE                      7.00%
       GENERAL INFLATION RATE                     4.00%
       STUMPAGE PRICE INFLATION RATE              1.20%
       BASE YEAR FOR THE ANALYSIS                 1987
       END YEAR FOR THE ANALYSIS                  2007


 DIARY OF COST AND REVENUE ACTIVITIES:

          (ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

 ENTRY     NAME          YEAR(S)        COST      REVENUE    INFLATION RATE

   1     Buy Land         1987         300.00        .00          .00
   2     Property Tax   1987-2007         .90        .00          .00
   3     Sale Prep.       1987          65.00        .00          .00
                          2007          65.00        .00          .00
   4     Sale Admin.      1987          22.00        .00          .00
                          2007          22.00        .00          .00
   5     Sell Land        2007            .00     300.00          .00
   6     SALE INCOME      1987            .00      82.95         1.20
   7     SALE INCOME      2007            .00     987.07         1.20
```

Figure 14.—*Portion of a cash flow table.*

```
PROFILE OF NET PRESENT VALUE (NPV) FOR  THE  INVESTMENT  AT  VARIOUS  DISCOUNT
RATES
                         (INVESTMENT LENGTH =  21 YEARS)

                   (NPV VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

       REAL RATE             NOMINAL RATE                   NPV

-------------------------------------------------------------------------------
            .00%                  4.00%               $   1143.06
           2.00%                  6.08%               $    666.91
           4.00%                  8.16%               $    351.89
           6.00%                 10.24%               $    141.83
           8.00%                 12.32%               $       .75
          10.00%                 14.40%               $    -94.70
          12.00%                 16.48%               $   -159.69
          14.00%                 18.56%               $   -204.24
          16.00%                 20.64%               $   -234.95
          18.00%                 22.72%               $   -256.25
          20.00%                 24.80%               $   -271.09
          22.00%                 26.88%               $   -281.49
          24.00%                 28.96%               $   -288.80
          26.00%                 31.04%               $   -293.96
          28.00%                 33.12%               $   -297.62
          30.00%                 35.20%               $   -300.22
          32.00%                 37.28%               $   -302.07
          34.00%                 39.36%               $   -303.38
          36.00%                 41.44%               $   -304.32
          38.00%                 43.52%               $   -304.98
          40.00%                 45.60%               $   -305.44
          42.00%                 47.68%               $   -305.77
          44.00%                 49.76%               $   -305.99
          46.00%                 51.84%               $   -306.15
          48.00%                 53.92%               $   -306.25
          50.00%                 56.00%               $   -306.31
```

Figure 15.—*Profile of net present values.*

```
                    INVESTMENT PERFORMANCE ANALYSIS

   NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                    (INVESTMENT LENGTH =  21 YEARS)

        (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

----------------------------------------------------------------------
      NET PRESENT VALUE (NPV)                             $    511.62

      EQUIVALENT ANNUAL INCOME (EAI)                      $     34.02

      SOIL EXPECTATION VALUE (SEV)                        $   1179.49

      BENEFIT/COST RATIO                                         2.14

      YEARS TO PAY BACK AT DISCOUNT                          20 YEARS

      REAL INTERNAL RATE OF RETURN                               8.01%

      NOMINAL INTERNAL RATE OF RETURN                           12.33%
```

Figure 16.—*Project performance table.*

```
                        SENSITIVITY ANALYSIS

      (SENSITIVITY OF PERFORMANCE TO A 10% CHANGE IN INPUT VALUES)
   NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                    (INVESTMENT LENGTH =  21 YEARS)

        (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

  ITEM CHANGED       NPV CHANGE        EAI CHANGE        SEV CHANGE
----------------------------------------------------------------------
  Buy Land        $      30.00    $        2.00    $        69.16
  Property Tax    $       1.44    $         .10    $         3.33
  Sale Prep.      $      10.18    $         .68    $        23.47
  Sale Admin.     $       3.45    $         .23    $         7.94
======================================================================
  Sell Land       $      16.99    $        1.13    $        39.16
  SALE INCOME     $       8.30    $         .55    $        19.12
  SALE INCOME     $      70.95    $        4.72    $       163.57
```

Figure 17.—*Sensitivity of three performance measures.*

```
                              RISK ANALYSIS


        (INPUT VALUE CHANGES WHICH WILL MAKE NPV EXACTLY EQUAL TO $0.00)
     NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                      (INVESTMENT LENGTH =  21 YEARS)

            (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

    ITEM CHANGED              PERCENT CHANGE             DOLLAR CHANGE
--------------------------------------------------------------------------
    Buy Land                     100.00%               $      -300.00
    Property Tax                 100.00%               $       -14.43
    Sale Prep.                   100.00%               $      -101.81
    Sale Admin.                  100.00%               $       -34.46
==========================================================================
    Sell Land                   -100.00%               $      -169.87
    SALE INCOME                 -100.00%               $       -82.95
    SALE INCOME                  -72.11%               $      -511.62
```

Figure 18.—*Risk analysis table.*

Stand Summary Report

Before growth and management are simulated, TWIGS presents a stand conditions table (fig. 19) and, if you chose the volume option, stand volumes (fig. 20). If in the run options, you decided not to use the management and economics components, go to the Growth Simulation section on page 25. If you selected to use economics only, go to the Economics and Management Repeated section on page 23. For users managing the stand, proceed to the following section on management.

Management

During management, the screen displays the current stand statistics and a management menu (fig. 21), and you select actions from the menu. TWIGS will make any indicated cut and print a record of the cut. The current stand statistics are displayed after each cut. The menu is shown again so you can continue with the projection or simulate another management action to refine the previous action or experiment with several actions.

Note: if you chose to use the economic option, then in this component, when all management is completed for the growth cycle, the stumpage value of all trees cut during the cycle is computed and automatically entered into a diary of cost and revenue activities for economic analysis. The sale income and the residual stand value will be shown on a per acre basis for saw logs, pulpwood, residue, and total volumes.

Step 7
Management Decision. Indicate if you will manage or skip management. If you choose not to manage, go to step 10.

Within the management component of TWIGS, users may view selected stocking guides that allow visual tracking of management effects on basal area and number of trees per acre. Using this stocking guide option (action K) requires either a graphics monitor or a graphics card for a monochrome monitor.

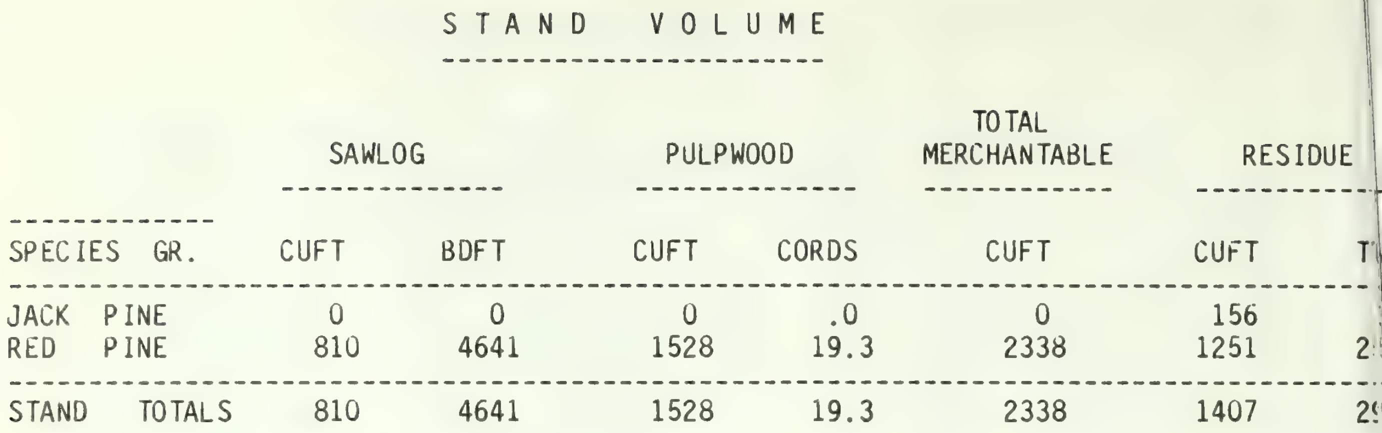
Step 8
Graphics Capabilities. The first time management is accessed, indicate if you have graphics capabilities (graphic monitor or a graphics card for a monochrome monitor).

Step 9
Management Simulation. The current stand statistics and management menu are displayed (fig. 21), and you select from the options. When management has been completed, press "Z" to continue the projection.

Current Stand Statistics.—These statistics describe live and cut trees on a per acre basis. The statistics presented are: number of trees

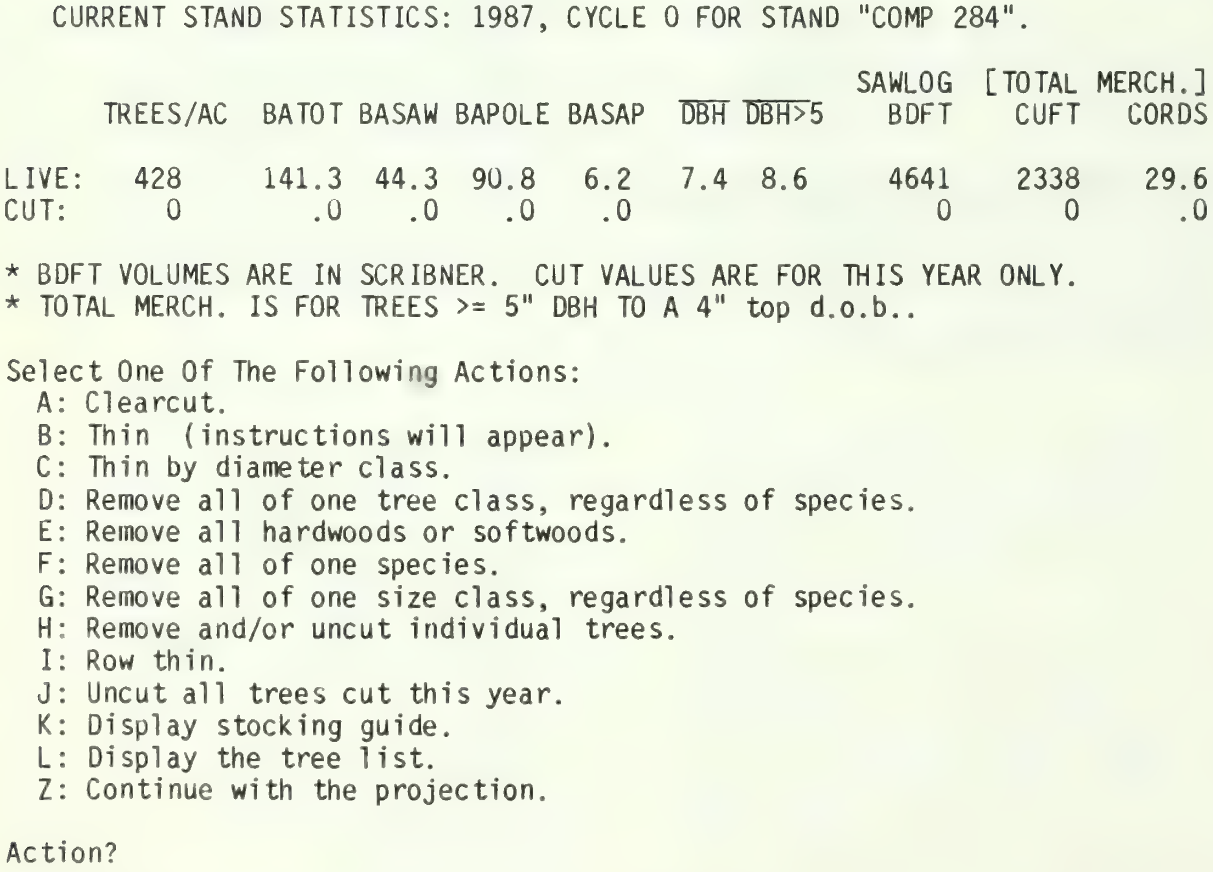
```
REPORT FOR STAND "BACK40".   YEAR= 1987.  INITIAL CONDITIONS.
AGE= 30,  CYCLE= 0,  SITE INDEX FOR RED PINE  =  60.0

                                                     CUT           MORTALITY
                  LIVE       BA/   AVG   AVG   -------------   ------------- GROUP
SPECIES GR.     TREE/AC     ACRE   DBH   CAI   TREE/AC BA/AC   TREE/AC BA/AC   SI
--------------------------------------------------------------------------------
JACK PINE
 .0-  4.9          95        6.2   3.4   .00     0       .0       0      .0  60.0
5.0-10.9           0         .0    .0   .00     0       .0       0      .0
11.0+              0         .0    .0   .00     0       .0       0      .0

GROUP TOTALS      95        6.2   3.4   .00     0       .0       0      .0


RED PINE
 .0- 4.9           0         .0    .0   .00     0       .0       0      .0  60.0
5.0-10.9          332      133.9   8.6   .00     0       .0       0      .0
11.0+              2        1.1  11.8   .00     0       .0       0      .0

GROUP TOTALS      333      135.1   8.6   .00     0       .0       0      .0


--------------------------------------------------------------------------------
ALL SPECIES
 .0- 4.9           95        6.2   3.4   .00     0       .0       0      .0
5.0-10.9          332      133.9   8.6   .00     0       .0       0      .0
11.0+              2        1.1  11.8   .00     0       .0       0      .0

--------------------------------------------------------------------------------
STAND TOTALS      428      141.3   7.4   .00     0       .0       0      .0

CAI = CURRENT ANNUAL DIAMETER INCREMENT.
```

Figure 19.—*Stand conditions table.*



```
                     S T A N D   V O L U M E
                     -----------------------

                                                        TOTAL
                  SAWLOG              PULPWOOD       MERCHANTABLE      RESIDUE
              --------------      --------------     ------------     ----------
-------------
SPECIES  GR.    CUFT     BDFT      CUFT    CORDS         CUFT          CUFT     T
--------------------------------------------------------------------------------
JACK  PINE         0        0         0       .0            0           156
RED   PINE       810     4641      1528     19.3         2338          1251     2
--------------------------------------------------------------------------------
STAND   TOTALS   810     4641      1528     19.3         2338          1407     2

BDFT VOLUMES ARE IN INT. 1/4.

MEAN ANNUAL INCREMENT = 77.9 CUFT/YEAR.
```

Figure 20.—*Volume table.*



```
     CURRENT STAND STATISTICS: 1987, CYCLE 0 FOR STAND "COMP 284".

                                                        SAWLOG  [TOTAL MERCH.]
        TREES/AC  BATOT BASAW BAPOLE BASAP  DBH DBH>5    BDFT     CUFT   CORDS

  LIVE:   428     141.3  44.3  90.8   6.2   7.4  8.6     4641     2338    29.6
  CUT:      0        .0    .0    .0    .0                   0        0      .0

  * BDFT VOLUMES ARE IN SCRIBNER.  CUT VALUES ARE FOR THIS YEAR ONLY.
  * TOTAL MERCH. IS FOR TREES >= 5" DBH TO A 4" top d.o.b..

  Select One Of The Following Actions:
    A: Clearcut.
    B: Thin  (instructions will appear).
    C: Thin by diameter class.
    D: Remove all of one tree class, regardless of species.
    E: Remove all hardwoods or softwoods.
    F: Remove all of one species.
    G: Remove all of one size class, regardless of species.
    H: Remove and/or uncut individual trees.
    I: Row thin.
    J: Uncut all trees cut this year.
    K: Display stocking guide.
    L: Display the tree list.
    Z: Continue with the projection.

  Action?
```

Figure 21.—*Management menu with current stand statistics table.*

(TREES/AC), total basal area (BATOT), basal area for sawtimber (BASAW), poles (BAPOLE), and saplings (BASAP), average d.b.h. ($\overline{DBH}$), and average d.b.h. for trees more than 5 inches d.b.h. ($\overline{DBH} > 5$). Volume is included in board feet for saw logs and in cubic feet and cords for trees more than 5 inches d.b.h. to a 4-inch top d.o.b., excluding culls but including undesirable trees (fig. 3).

Management Menu.–This menu offers the following actions to choose from:

Action A clearcuts the stand. If you change your mind, use option J to bring the trees back to life.

Action B prompts a series of options to thin:

a. from above, below, or by tree list order,
b. to favor (leave) certain species,
c. to a prescribed basal area,
d. to a prescribed number of trees/acre, and
e. to an upper and/or lower diameter limit.

You will be given all options, although some may not apply to the actions you are taking. When an option is not applicable, press "enter" or "new line." Any combination of options may be specified; but cutting stops when any one of the thinning specifications has been met. For instance, if the user has decided the stand will be thinned from below (a), back to 90 square feet per acre of residual basal area (c), to an upper diameter limit of 11 inches (e), then TWIGS will cut the smallest tree on the tree list first, regardless of species, until it reaches 90 square feet residual *OR* an 11-inch tree.

Action C thins by the diameter classes specified in the run options (option I). Within each diameter class, the thin options apply that were described above in action B.

Action D removes acceptable, undesirable, or cull tree-classes from the tree list. All trees of a selected class are removed regardless of species.

Action E removes all softwoods or hardwoods from the tree list.

Action F removes all of any species specified from the tree list.

Action G removes all of one size-class from the tree list. Upper and lower diameter limits are specified by the user.

Action H simulates a selection cut. Each tree list entry is displayed, one at a time on the screen, and you have the option to:

a. leave the tree as is,
b. cut all or part of the trees/acre represented by the entry,
c. uncut the tree if it was previously cut during this management period, and
d. skip the rest of the tree list.

Running tallies of remaining basal area and trees per acre are kept on the screen.

Action I simulates a row thin. You determine the proportion of the stand to cut (that is, every other row, every third row, or a certain percent of the stand). TWIGS will split every tree list entry and will assign cut status to the specified proportion of the tree's expansion factor. As a result, when action I is selected, the number of entries on the tree list doubles.

Action J uncuts the trees that were cut during the current management period. By cutting and uncutting trees, you can examine the effects of several alternative prescriptions within a growth cycle.

Action K displays selected stocking guides on the screen or on the screen and printer. The stocking guides available in TWIGS are:

Lake States:
  Aspen (Perala 1986)
  Oak (Gingrich 1967)
  Jack pine (Benzie 1977a)
  Red pine (Benzie 1977b)
  White pine (Philbrook *et al.* 1973)
  White spruce (Benzie and Rauscher 1987)
Central States:
  Oak (Gingrich 1967)
  Shortleaf pine (Rogers 1983)

The number of the projection cycle in which the stocking guide is called is used to mark the stocking level. Figure 22 shows a stocking guide that was called before the stand was grown (projection cycle 0), thus a "0" is used to indicate the stocking level. More than one growing-stock-level marker indicates the levels before and after cutting.

Action L displays the current tree list so you can see which entries have been cut and how each entry has increased in diameter.

Action Z ends the management process with an "after management" stand report and then continues the projection.

Economics and Management Repeated

If you did not select either the management or economics components, go on to the Growth Simulation section. If you indicated in the run options that

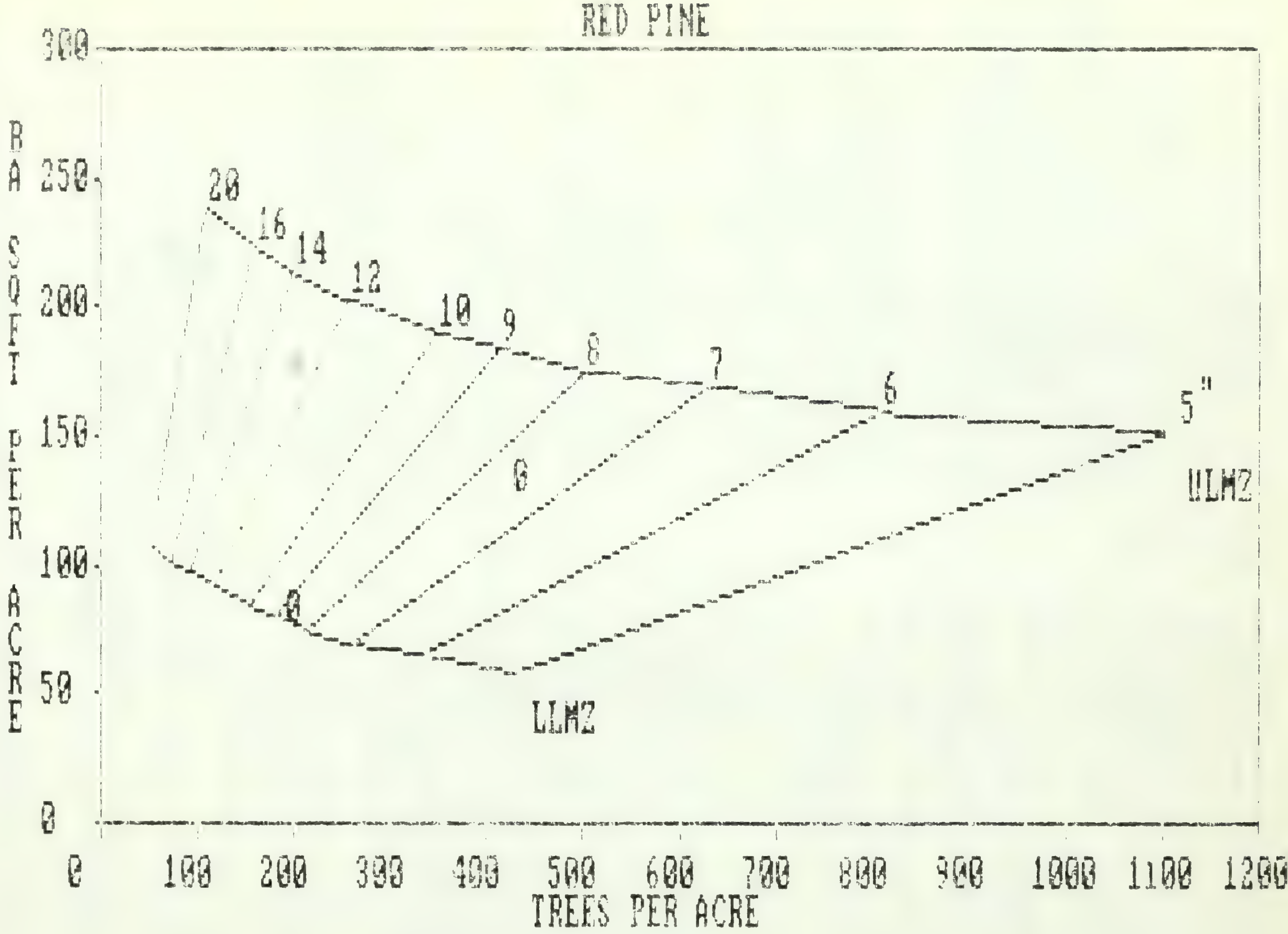


Figure 22.—*Red pine stocking guide. Zero's (0) mark the stocking level before and after cutting.*

the management and economics components were to be used, then the TWIGS program will offer options for going back to the economic and management components as many times as necessary within a growth cycle to examine management and economic alternatives and their effects on stand conditions and economic values.

Step 10
Economic/Management Sequence. Indicate if you want to redo the management/economics sequence. If you press "Y," go to step 6; if you press "N," proceed to the growth simulation component or to ingrowth component, depending on which growth cycle you are in.

Growth Simulation

TWIGS presents a banner that identifies the cycle, the year, the number of growth intervals, and the number of years in the growth cycle. The program then applies the growth and mortality equations, and stand growth is projected as indicated in the run options. Next, after you press enter, the stand summary table is presented (fig. 19).

For those who selected management and economics in the run options, you are given the option to manage and later to do an economics analysis (steps 7 to 10), to do only an economic analysis (step 6), and to redo the management/economic sequence. When none of these options are selected, go to the following section on ingrowth.

Ingrowth

At the end of each growth cycle, you have the opportunity to add ingrowth trees to the stand being projected. In TWIGS, "ingrowth" refers to those trees that naturally enter the stand and are at least 1-inch d.b.h. TWIGS gives no guidelines about what species, what size, or how many trees would likely appear in the particular stand being simulated, but does give the user the opportunity to supply this information. The information can be based on actual data, or it can be hypothetical. The sample trees entered are automatically added to the bottom of the tree list being projected; in future growth cycles these trees are grown, killed, and cut along with the rest of the trees on the list.

Step 11
Ingrowth. Press "Y" to add trees into the stand. If you decide to add ingrowth trees, TWIGS prompts for the following information (which is the same data needed for the TREEGEN program to generate a tree list).

- Forest Service species code (appendix A),
- tree d.b.h. in inches,
- crown ratio (optional),
- number of trees per acre,
- tree status (live, dead, or cut), and
- tree class (acceptable, undesirable, or cull).

In ingrowth, after you have finished adding all trees, you may change stand age and see a list and report of the trees you added into the stand.

Continuation and Completion

Following are the steps for further developing and completing the TWIGS run. If you have more growth cycles to complete, go to step 12. If this is your last growth cycle, go to step 14.

Step 12
Run Options. Change run options (fig. 7), if you wish. Note at this point that you can discontinue the TWIGS run with option "J."

Step 13
Go to growth simulation component.

Step 14
Growth cycles and tree list file. When the growth cycles that were requested in the run options are completed, you will have the option to add more growth cycles and go to step 12. If you decide not to add other cycles, you will be given the option to write the tree list to another file, run TWIGS again, or end the program.

Summary of Management and Growth Projection

A summary of the entire TWIGS run (fig. 23) is printed at the completion of a run, regardless of

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                    ::
::              SUMMARY OF MANAGEMENT AND GROWTH PROJECTION           ::
::                                                                    ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Stand Description:
------------------
Stand Name: COMP 284
Initial Year of Projection: 1987
Initial Age:  56
Site Index Species: RED PINE          Site Index: 55.0

Management Applied:
-------------------

 Thin, from below to  90 square feet of basal area in 1987
 Clearcut in 2007

                                                        VOLUME
                                          ----------------------------------
                                            SAWLOG      PULPWOOD    RESIDUAL
            MGMT    TREES/AC   BA/   AVG  -----------  ----------  ----------
YEAR  AGE  STATUS  LIVE DIED   AC    DBH  CUFT   BDFT  CUFT  CORD  CUFT  TONS
------------------------------------------------------------------------------
1987   56  BEFORE  308     0  133    8.6  1671   8268   720     9  1283    27
1987   56  CUT     150     0   43     .0   224   1094   436     6   347     8
1987   56  AFTER   158     0   90   10.1  1447   7174   284     4   936    19


1997   66  BEFORE  158     0  117   11.5  2297  11511   111     1  1310    26


2007   76  BEFORE  157     0  142   12.8  2903  15534   157     2  1676    33
2007   76  CUT     157     0  142     .0  2903  15534   157     2  1676    33
2007   76  AFTER     0     0    0     .0     0      0     0     0     0     0
```

Figure 23.—*Summary table of the management and growth projection.*

which options you select in step 14. The stand is identified and described by initial year of projection, initial age, and site index. Management is summarized in a short description and in a table that shows stand information before and after management.

SUMMARY

TWIGS is an individual-tree, growth-and-yield microcomputer program developed for forest species of and conditions in the Central and Lake States. The program was designed as a decisionmaking tool for natural resource professionals and is also suitable as a forestry demonstration and teaching tool.

The individual-tree growth model for TWIGS uses both diameter growth (as a product of potential growth where little or no competition exists) and a competition modifier to project growth. Natural mortality is estimated from tree species, size, and vigor. Volumes for saw logs, pulpwood, and residue are calculated by species groups.

Initially, a companion program, TREEGEN, is used to create a tree list for TWIGS. The user enters this tree list and interactively adds values and parameters for growth, management, and

conomics into TWIGS. TWIGS simulates manage-
ent as the user indicates and provides an evalua-
ion of the effects of each management prescription
om a productivity and economic basis. Selective
utting, row thinning, clearcutting, and a variety
f other management actions can be chosen so that
lmost any cutting scenario can be examined.

With inputs such as stumpage-price rates,
tumpage-price inflation rate, discount rate, and
osts (annual or one-time), the economic component
rovides real or nominal economic analyses.
conomic performance measures are net present
alue, equivalent annual income, soil expectation
alue, benefit/cost ratio, payback period, and real
nternal rate of return. Other outputs include risk
nalysis and cash-flow tables.

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APPENDIX A

TREE SPECIES AND SPECIES GROUP CODES

Lake States TWIGS

GROUP CODE	SPECIES CODE	SPECIES
1	105	jack pine
	130	scotch pine
2	125	red pine
3	129	white pine
4	94	white spruce
5	12	balsam fir
6	95	black spruce
7	71	tamarack
8	241	northern white cedar
9	261	hemlock
10	001	other softwoods*
11		black-green ash
	543	black ash
	544	green ash
12	742	cottonwood
13	317	silver maple
14	316	red maple
15		elm
	972	american elm
	975	red elm
	977	rock elm
16	371	yellow birch
17	951	basswood

GROUP CODE	SPECIES CODE	SPECIES
18		hard maple
	318	sugar maple
	314	black maple
19	541	white ash
20		white oaks
	802	white oak
	804	swamp white oak
	823	burr oak
	826	chinkapin oak
21		select red oak
	833	northern red oak
22		other red oak
	837	black oak
	809	northern pin oak
23		hickory
	402	bitternut hickory
	403	pignut hickory
	407	shagbark hickory
24	743	bigtooth aspen
25	746	quaking aspen
	741	balsam poplar
26	375	paper birch
27-29		(not used)
30	300	other hardwoods*
31	999	noncommercial spp.

*Any USFS species not listed here is put into "other softwoods" if USFS code <300 or into "other hardwoods" if USFS code ≥ 300.

Central States TWIGS

GROUP CODE	SPECIES CODE	SPECIES
1	068	eastern redcedar
	060	juniper
2	110	shortleaf pine
3	132	virginia pine
	131	loblolly pine
4		other softwoods
	129	white pine
5		(not used)
6		walnut
	602	black walnut
	601	butternut

GROUP CODE	SPECIES CODE	SPECIES
7		tupelo
	694	swamp tupelo (blackgum)
	691	water tupelo
	693	black tupelo
8		select hickory
	407	shagbark hickory
	405	shellbark hickory
	409	mockernut hickory

Central States TWIGS

GROUP CODE	SPECIES CODE	SPECIES
9		other hickory
	403	pignut hickory
	400	hickory spp.
	401	water hickory
	402	bitternut hickory
	404	pecan
	408	black hickory
10		beech
	531	american beech
11	543	black ash
	545	pumpkin ash
	546	blue ash
12	742	cottonwood
13		soft maple
	316	red maple
	313	boxelder
	317	silver maple
14		cherry
	762	black cherry
15		elm
	972	american elm
	461	sugarberry
	462	hackberry
	971	winged elm
	970	elm spp.
	974	Siberian elm
	975	red elm
	977	rock elm
16	621	yellow poplar
17		basswood
	951	american basswood
18		hard maple
	318	sugar maple
19		white and green ash
	541	white ash
	540	ash spp.
	544	green ash
20	802	white oak
21		red oak
	833	northern red oak
	812	southern red oak
22	837	black oak
23	806	scarlet oak
24	824	blackjack oak
25	826	chinkapin oak
	804	swamp white oak
	823	bur oak
	825	swamp chestnut oak
26	835	post oak
	836	Delta post oak
27	832	chestnut oak
28	830	pin oak
	809	northern pin oak
	813	cherrybark oak
	817	shingle oak
	822	overcup oak
	827	water oak
	828	Nuttall oak
	831	willow oak
	834	Shumard oak
29		other upland hardwoods
	931	sassafras
	331	Ohio buckeye
	452	catalpa
	521	persimmon
	550	honey locust spp.
	552	honey locust
	741	balsam poplar
	743	bigtooth aspen
	746	quaking aspen
	901	black locust
30		other lowland species
	731	sycamore
	221	baldcypress
	373	river birch
	611	sweetgum
	920	willow spp.
	922	black willow
31		noncommercial species
	999	misc. noncommercial
	391	blue beech
	471	redbud
	491	dogwood spp.
	500	hawthorn spp.
	571	Kentucky coffeetree
	641	osage orange
	651	cucumber tree
	653	sweetbay
	680	mulberry
	681	white mulberry
	682	red mulberry
	701	ironwood
	711	sourwood

APPENDIX B

GROWTH, MORTALITY, AND CROWN RATIO EQUATIONS AND COEFFICIENTS

LAKE STATES

GROWTH EQUATION AND COEFFICIENTS

Annual Diameter Growth = Potential Growth * Competition Modifier + Diameter Adjustment Factor

$$\text{Potential Growth} = b_1 + b_2D^{b_3} + b_4\text{SI CR } D^{b_5} \qquad [B1]$$

Where:

Potential growth = potential annual d.b.h. growth (inches/yr);
D = current tree diameter (d.b.h. in inches);
SI = site index (feet at age 50);
CR = tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9); and
$b_1,\ldots,b_5$ = species specific equation coefficients from Table B1.

Source: Hahn and Leary (1979)

Table B1. Coefficients to calculate potential growth in Lake States TWIGS, equation B1.

Lake States					
Species Group	b_1	b_2	b_3	b_4	b_5
1	.16062	-.0000090	3.6245	.00004000	1.0000
2	.09446	-.0001200	2.0596	.00035000	.2423
3	.25578	-.0008800	1.7263	.00004000	1.0000
4	.17056	-.0145160	1.0660	.00052000	.2730
5	.12200	-.0008000	1.9890	.00006000	1.0000
6	.10713	-.0010700	2.0017	.00006000	.9113
7	.11147	-.0000100	3.0685	.00003000	1.0000
8	.13403	-.0000010	3.6880	.00002000	1.0000
9	.16872	-.0000003	3.5738	.00001000	1.0000
10	.16062	-.0000090	3.6245	.00004000	1.0000
11	.05881	.0000000	5.0559	.00024000	.3155
12	.10948	-.0000400	2.2226	.00050000	.0663
13	.10948	-.0000400	2.2226	.00050000	.0663
14	.10948	-.0000400	2.2226	.00050000	.0663
15	.28496	-.0018200	1.5297	.00003000	1.0000
16	.15155	-.0000030	3.3104	.00007000	.5730
17	.25402	-.0000040	2.9396	.00001000	1.0000
18	.18772	-.0000070	2.5839	.00028000	.0839
19	.21167	-.0000030	3.3131	.00001000	.1243
20	.12654	-.0000040	2.7538	.00005000	.6209
21	.15535	-.0000001	3.5367	.00018000	.2590
22	.17358	-.0000700	2.4451	.00003000	.9522
23	.16471	-.0021610	1.3949	.00004000	.7163
24	.23490	-.0094200	1.1041	.00036000	.1539
25	.21645	-.0000910	2.6030	.00004400	1.0000
26	.10971	-.0003200	2.0236	.00034000	.2129
27	.37510	-.0247900	.9629	.00004000	1.0000
28	.37510	-.0247900	.9629	.00004000	1.0000
29	.37510	-.0247900	.9629	.00004000	1.0000
30	.37510	-.0247900	.9629	.00004000	1.0000
31	.37510	-.0247900	.9629	.00004000	1.0000

MODIFIER EQUATION AND COEFFICIENTS

$$\text{Competition Modifier} = 1 - e^{-f(R)g(AD)[(BA_{max} - BA)/BA]^{1/2}} \qquad [B2]$$

Where:

Competition modifier = an index of competition, always bounded between zero and one;

BA_{max} = maximum basal area (ft^2/acre) expected for the species (Table B2);

BA = current basal area (ft^2/acre);

R = relative d.b.h. of the tree (ratio of the tree's d.b.h. to the average stand diameter);

AD = average stand diameter (inches);

f(R) = a function characterizing the individual tree's relative diameter effect on the modifier

$$f(R) = b_1[1 - e^{b_2 R}]^{b_3} + b_4;$$

g(AD) = a function characterizing the average stand diameter effect on the modifier,

$$g(AD) = c_1(AD + 1)^{c_2}; \text{ and}$$

$b_1,\ldots,b_4,c_1,c_2$ = species specific equation coefficients from Table B2.

Source: Holdaway (1984)

Table B2. Coefficients to calculate the competition modifier for Lake States TWIGS, equation B2.

Lake States							
Species Group	BA_{max}	b_1	b_2	b_3	b_4	c_1	c_2
1	225.0	1.7800	-3.000	16.20	.2270	40200	.2300
2	300.0	.7190	-10.900	1688.00	.3750	2.03000	-.3540
3	300.0	1.3600	-2.640	11.50	.3860	.09700	.7550
4	350.0	5.0000	-1.010	3.64	.0000	1.50700	-.5200
5	325.0	1.7600	-1.510	2.63	.2330	.92700	-.2990
6	300.0	3.8000	-1.520	6.54	.3480	.52200	.1730
7	250.0	1.7800	-3.000	16.20	.2270	.03900	1.0000
8	350.0	2.5400	-1.140	2.26	.0000	.52600	.1360
9	300.0	1.2700	-1.340	1.05	.0000	.04600	1.0000
10	300.0	1.3600	-2.640	11.50	.3860	.09700	.7550
11	250.0	5.0000	-.568	1.83	.0630	.26000	.4190
12	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
13	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
14	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
15	250.0	5.0000	-.970	4.40	.2680	.10000	.6290
16	250.0	.6790	-10.970	1568.00	.4830	.20200	.4540
17	325.0	1.5900	-3.270	26.70	.4120	.35300	.1820
18	250.0	1.1700	-4.590	29.19	.4300	.14200	.5240
19	250.0	5.0000	-1.380	8.26	.3260	.45300	.3400
20	300.0	1.9800	-.974	1.64	.0000	.05100	1.0000
21	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
22	250.0	1.9800	-.974	1.64	.0000	1.36500	-.2080
23	250.0	1.6600	-2.620	9.97	.5150	.28000	.2280
24	250.0	1.1300	-4.640	164.60	.6480	.09300	1.0000
25	250.0	1.0800	-6.600	346.10	.3950	.20900	.5430
26	275.0	1.9800	-1.750	3.67	.2320	.11000	.6780
27	350.0	2.3100	-1.670	3.94	.0000	.44100	.1730
28	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
29	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
30	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
31	275.0	1.9800	-.974	1.64	.0000	.27800	.3650

$$\text{Diameter Adjustment Factor} = a_1 D + a_2 D^2 + a_3 \qquad [B3]$$

Where:

Diameter adjustment factor = adjustment in annual d.b.h. growth (inches/yr);

D = current tree diameter (d.b.h. in inches); and

a_1, a_2, a_3 = species specific equation coefficients from Table B3.

Source: Holdaway (1985).

Table B3. Coefficients to calculate the diameter adjustment factor for Lake States TWIGS, equation B3.

Lake States			
Species Group	a_1	a_2	a_3
1	-.0174	.00065	.069
2	.0000	-.00017	.018
3	-.0043	.00011	.029
4	.0000	.00000	.000
5	-.0112	.00040	.030
6	-.0248	.00162	.037
7	-.0093	.00042	.048
8	-.0050	.00000	-.004
9	-.0043	.00022	.039
10	.0000	.00000	.000
11	-.0115	.00032	.051
12	.0000	.00000	.000
13	.0109	.00000	-.106
14	.0008	.00004	-.017
15	-.0102	.00023	.028
16	-.0021	.00010	.001
17	.0000	.00007	-.037
18	.0014	.00002	-.024
19	-.0113	.00066	-.002
20	-.0079	.00039	.048
21	.0015	-.00003	-.026
22	.0026	.00000	-.088
23	.0000	.00000	.000
24	.0124	-.00022	-.079
25	-.0132	.00079	.031
26	-.0066	.00038	.011
27	.0000	.00000	.000
28	.0000	.00000	.000
29	.0000	.00000	.000
30	.0085	-.00026	-.088
31	-.0046	.00000	-.070

CROWN RATIO EQUATION AND COEFFICIENTS

$$CR = \frac{b_1}{1 + b_2 RBA} + b_3 \left[1 - e^{b_4 D}\right] + CF \qquad [B4]$$

Where:

CR = individual tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9);
RBA = 10-year running average stand basal area (ft^2/ac);
D = current tree diameter (d.b.h. in inches);
CF = correction factor computed as: initial predicted CR - initial observed CR; and
$b_1, \ldots, b_4$ = species specific equation coefficients from Table B8.

Source: USDA Forest Service (1983)

Table B8. Coefficients to calculate crown ratio code for Central States TWIGS, equation B4.

	Central States			
Species Group	b_1	b_2	b_3	b_4
1	4.0862	.009553	4.230	-.65539
2	3.8229	.015548	3.670	-.09307
3	3.8229	.015548	3.670	-.09307
4	3.8229	.015548	3.670	-.09307
5	.0000	.000000	.000	.00000
6	5.3258	.005879	187.864	-.00032
7	3.5960	.024137	3.378	-.56073
8	4.0007	.013160	3.241	-1.05537
9	4.0007	.013160	3.241	-1.05537
10	3.7332	.004015	3.632	-.04124
11	4.7419	.074792	3.327	-.87106
12	4.5860	.004527	4.275	-.01943
13	4.7334	.005145	1.549	-.19205
14	3.7332	.004015	3.632	-.04124
15	4.2114	.000570	2.492	-.02658
16	3.7332	.004015	3.632	-.04124
17	3.7332	.004015	3.632	-.04124
18	4.5228	.004882	2.324	-.22893
19	4.7419	.074792	3.327	-.87106
20	4.6207	.004194	2.627	-.16836
21	4.6941	.005722	2.046	-.23262
22	5.6002	.007243	1.713	-.16631
23	4.1573	.010524	2.618	-.46232
24	3.6371	.009565	3.058	-.60477
25	4.1897	.008983	3.391	-.15663
26	3.6936	.003876	2.733	-.23391
27	5.8825	.008243	332.983	-.00022
28	1.9729	.037414	5.315	-1.07581
29	3.7332	.004015	3.632	-.04124
30	4.5860	.004527	4.275	-.01943
31	4.3510	.001539	110.671	-.00154

MORTALITY EQUATION AND COEFFICIENTS

$$\text{Survival} = b_1 - [1/(1 + e^{n})] \qquad [B5]$$

Where:

Survival = the trees' annual probability of survival;

$n = b_2 + b_3 DGR^{b_4} + b_5(D-1)^{b_6} e^{-b_7(D-1)}$;

DGR = predicted annual diameter growth (inches);

D = current tree diameter (d.b.h. in inches); and

$b_1,\ldots,b_7$ = species specific equation coefficients from Table B5.

Source: Buchman, et al. (1983), Buchman (1983), Buchman and Lentz (1984)

Table B5. Coefficients to calculate survival rate in Lake States TWIGS, equation B5.

	Lake States						
Species Group	b_1	b_2	b_3	b_4	b_5	b_6	b_7
1	.9966	.5902	18.00	.7110	.01144	4.7640	.6834
2	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
3	.9989	1.6150	1568.00	2.2680	.87120	.4320	.1012
4	.9994	.9724	314.20	1.9150	.28386	1.3021	.1683
5	.9984	1.9241	28.71	1.0210	4.42100	3.6400	1.6720
6	.9946	1.6990	53.78	1.2190	.68277	.9598	.2250
7	.9970	1.6807	53.78	1.2190	.68277	.9598	.2250
8	.9990	2.2089	86.74	1.0000	.19312	1.5881	.2157
9	.9991	3.0762	27.14	1.1006	.06678	3.4908	.4888
10	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
11	.9990	1.6657	53.78	1.2190	.68277	.9598	.2250
12	.9964	1.0260	368.59	1.7248	.34484	1.9680	.2919
13	.9964	1.0260	368.59	1.7248	.34484	1.9680	.2919
14	.9964	1.0260	368.60	1.7250	.34480	1.9680	.2919
15	.9941	.5794	11.63	.6440	.26550	2.9630	.4715
16	.9975	2.2028	19.11	.8298	1.51710	2.1691	.7958
17	.9979	1.1097	28.39	1.0450	.40350	2.0390	.2769
18	.9979	2.4852	60.76	1.2050	.85030	1.0100	.2394
19	.9992	1.3148	1392.50	2.4835	.03413	4.9703	.8110
20	.9994	2.2907	1000.00	1.8500	.06576	4.2280	.7366
21	.9977	.5639	29.09	1.1370	.01004	3.8340	.3177
22	.9977	.5638	29.09	1.1370	.01004	3.8340	.3177
23	.9980	2.0115	313.96	2.4521	.01149	4.1021	.3479
24	.9908	.3772	34.55	1.0886	.09314	3.4186	.5346
25	.9908	.3772	34.55	1.0890	.09314	3.4190	.5346
26	.9991	1.9539	8.38	.3982	1.71000	2.4440	.8923
27	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
28	1.0000	99.0000	1.00	1.0000	.10000	1.0000	1.0000
29	1.0000	99.0000	1.00	1.0000	.10000	1.0000	1.0000
30	.9928	2.1665	88.78	1.6255	.00295	4.8551	.5613
31	.9952	2.0387	153.60	1.2989	.33279	3.0610	.8202

CENTRAL STATES

GROWTH EQUATION AND COEFFICIENTS

Annual Tree Basal Area Growth = Potential Growth * Competition Modifier

$$\text{Potential Growth} = (b_1 BA^{b_2} - b_3 TBA)(b_4 + b_5 SI + b_6 CR) \qquad [B6]$$

Where:

Potential growth = potential tree basal area growth (ft^2/yr);
TBA = tree basal area (ft^2/tree);
SI = site index (feet at age 50);
CR = tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9); and
$b_1,\ldots,b_6$ = species specific equation coefficients from Table B6.

Source: USDA Forest Service (1983)

Table B6. Coefficients to calculate potential growth in Central States TWIGS, equation B6.

	Central States					
Species Group	b_1	b_2	b_3	b_4	b_5	b_6
1	.03922	.51499	.014859	.39742	.0007180	.074914
2	.03996	.14593	.009710	.82519	.0004757	.045452
3	.03996	.14593	.009710	.82519	.0004757	.045452
4	.03996	.14593	.009710	.82519	.0004757	.045452
5	.00000	.00000	.000000	.00000	.0000000	.000000
6	.06447	.43471	.010538	.08016	.0074174	.080557
7	.03503	.49430	.014747	.49661	.0077439	.000000
8	.05274	.55320	.018400	.42132	.0053480	.043101
9	.05274	.55320	.018400	.42132	.0053480	.043101
10	.09306	.64110	.030538	.62209	.0000000	.085091
11	.06565	.50860	.014956	.72314	.0003053	.058527
12	.13392	.54184	.030730	.75132	.0031739	.000000
13	.16952	.73000	.076330	.49370	.0057751	.004969
14	.09306	.64110	.030538	.62209	.0000000	.085091
15	.09366	.62629	.034261	.68951	.0043781	.004288
16	.07754	.59212	.016181	.61431	.0000000	.087708
17	.09306	.64110	.030538	.62209	.0000000	.085091
18	.04857	.61582	.014586	.85147	.0011077	.011213
19	.06565	.50860	.014956	.72314	.0003053	.058527
20	.06090	.55888	.013611	.73498	.0034682	.008474
21	.06332	.59455	.015945	.69043	.0038526	.011732
22	.07176	.53297	.018148	.79907	.0020395	.013021
23	.08797	.65940	.041193	.72584	.0013168	.034728
24	.03825	.54171	.013672	.85593	.0028003	.000000
25	.03628	.60465	.010894	.20651	.0068989	.073313
26	.04509	.62527	.021865	.67032	.0001721	.058600
27	.08655	.69260	.036875	.00627	.0127311	.026572
28	.08102	.41668	.013233	.09305	.0032289	.111761
29	.09306	.64110	.030538	.62209	.0000000	.085091
30	.13392	.54184	.030730	.75132	.0031739	.000000
31	.07158	.64291	.029430	.29425	.0012965	.139643

MODIFIER EQUATION AND COEFFICIENTS

$$\text{Competition Modifier} = b_9[1 - e^{-(b_7/BAL\ +\ b_8 D^2)(1\ -\ BA/200)^{1/2}}] \qquad [B7]$$

Where:

Competition modifier = an index of competition, always bounded between zero and one;
BAL = basal area (ft^2/acre) of all trees larger than this tree;
D = current tree diameter (d.b.h. in inches);
BA = stand basal area (ft^2/acre); and
b_7, b_8, b_9 = species specific equation coefficients from Table B7.

Source: USDA Forest Service (1983)

Table B7. Coefficients to calculate competition modifier for Central States TWIGS, equation B7.

	Central States		
Species Group	b_7	b_8	b_9
1	78.28	.015577	.63527
2	16.66	.008177	.70245
3	16.66	.008177	.70245
4	16.66	.008177	.70245
5	.00	.000000	.00000
6	109.46	.031778	.34065
7	44.06	.015989	.52659
8	46.40	.012405	.45019
9	46.40	.012405	.45019
10	68.78	.014203	.46704
11	41.56	.049642	.42627
12	53.18	.007198	.40176
13	48.53	.105569	.49498
14	68.78	.014203	.46704
15	46.11	.008685	.46063
16	.00	.310056	.64505
17	68.78	.014203	.46704
18	97.04	.025604	.60090
19	41.56	.049642	.42627
20	75.41	.006791	.49141
21	115.41	.007526	.62906
22	84.95	.002934	.51575
23	71.64	.002610	.74850
24	44.03	.009052	.70245
25	123.44	.046581	.52519
26	80.00	.008079	.59464
27	66.34	.002098	.58700
28	36.38	.008695	.62321
29	68.78	.014203	.46704
30	53.18	.007198	.40176
31	141.35	.013700	.35210

CROWN RATIO EQUATION AND COEFFICIENTS

$$CR = \frac{b_1}{1 + b_2 RBA} + b_3 \left[1 - e^{b_4 D}\right] + CF \qquad [B4]$$

Where:

CR = individual tree crown ratio code (0-10%=1, 11-20%=2,...71-80%=8, 81%+=9);
RBA = 10-year running average stand basal area (ft^2/ac);
D = current tree diameter (d.b.h. in inches);
CF = correction factor computed as: initial predicted CR - initial observed CR; and
$b_1,\ldots,b_4$ = species specific equation coefficients from Table B4.

Source: Holdaway (1986).

Table B4. Coefficients to calculate crown ratio code for Lake States TWIGS, equation B4.

	Lake States			
Species Group	b_1	b_2	b_3	b_4
1	6.64	.0135	3.200	-.0518
2	5.35	.0053	1.528	-.0330
3	6.79	.0058	7.590	-.0103
4	7.84	.0057	1.272	-.1420
5	5.63	.0047	3.523	-.0689
6	5.54	.0072	4.200	-.0530
7	6.00	.0053	.431	-.0012
8	5.71	.0077	2.290	-.2530
9	5.71	.0077	2.290	-.2530
10	5.71	.0077	2.290	-.2530
11	4.50	.0032	.795	-.1050
12	4.35	.0046	1.820	-.2740
13	4.85	.0050	9.810	-.0099
14	4.35	.0046	1.820	-.2740
15	4.40	.0025	1.000	-.0940
16	4.18	.0025	1.410	-.5120
17	4.44	.0037	2.090	-.0650
18	3.40	.0066	2.870	-.4340
19	4.49	.0029	1.210	-.0650
20	5.84	.0082	3.260	-.0490
21	4.20	.0016	2.760	-.0250
22	5.06	.0033	1.730	-.0610
23	6.21	.0073	9.990	-.0100
24	4.11	.0054	1.650	-.1100
25	4.00	.0024	-2.830	.0210
26	5.00	.0066	4.920	-.0263
27	4.00	.0024	-2.830	.0210
28	4.00	.0024	-2.830	.0210
29	4.00	.0024	-2.830	.0210
30	4.00	.0024	-2.830	.0210
31	4.00	.0024	-2.830	.0210

MORTALITY EQUATION AND COEFFICIENTS

$$\text{Survival} = 1 - [1/(1 + e^{n})] \qquad [B8]$$

Where:

Survival = the tree's annual probability of survival;

$n = c_1 + c_2(D + 1)^{c_3} e^{-c_4 D - c_5 BAL}$;

D = current tree diameter (d.b.h. in inches);

BAL = basal area (ft^2/acre) of all trees larger than this tree; and

$c_1,\ldots,c_5$ = species specific equation coefficients from Table B9.

Source: USDA Forest Service (1983)

Table B9. Coefficients to calculate probability of mortality for Central States TWIGS, equation B8.

	Central States				
Species Group	c_1	c_2	c_3	c_4	c_5
1	.0000	2.1313	1.2026	.16766	.006042
2	3.1106	.0116	4.1007	.37008	.012051
3	3.1106	.0116	4.1007	.37008	.012051
4	3.1106	.0116	4.1007	.37008	.012051
5	.0000	.0000	.0000	.00000	.000000
6	3.2101	.0123	2.1410	.05819	.000000
7	3.8940	16.7618	.4343	.21302	.046427
8	.0000	3.1518	.4444	.04833	.002578
9	.0000	3.1518	.4444	.04833	.002578
10	4.2508	.0043	2.4946	.06922	.014006
11	2.9379	.0127	3.3049	.24199	.008169
12	2.8282	.6661	.5506	.04233	.003375
13	3.4213	.0018	3.9486	.26708	.007647
14	2.8497	.0022	3.3528	.14147	.006456
15	1.7401	2.1316	.0000	.06621	.002796
16	3.4213	.0018	3.9486	.26708	.007647
17	2.8497	.0022	3.3528	.14147	.006456
18	4.2508	.0043	2.4946	.06922	.014006
19	2.9379	.0127	3.3049	.24199	.008169
20	.0000	2.9567	.5198	.03853	.003337
21	1.4669	1.6808	.6456	.05612	.003648
22	.0000	2.0325	.6311	.05430	.001745
23	.0000	1.9628	.8272	.08023	.006422
24	.3720	1.3479	.9159	.10719	.004255
25	2.2851	.0494	2.6376	.17328	.003045
26	1.1666	1.6463	.7875	.08305	.005003
27	.7915	1.4153	.9521	.07507	.007156
28	.0000	2.9198	.4006	.03519	.004352
29	2.8497	.0022	3.3528	.14147	.006456
30	2.8282	.6661	.5506	.04233	.003375
31	2.7525	.0061	10.3078	3.25895	.000000

APPENDIX C

ROUGH GUIDE TO RELIABILITY OF EQUATIONS

The tables below summarize the relation between species groups and the number of observations used to calibrate the equations for Lake and Central States TWIGS found in Appendix B. The column with the number of observations is provided as a rough indicator of the strength of the data base used to develop that particular set of equations. If no number is given, that species group uses the same projection equations as a larger group of which it is a subset.

The same set of observations was used for all three equations in Central States TWIGS. In Lake States TWIGS a different number of observations was used for each of the equations, therefore a range is presented. In general, the more observations available to develop an equation set, the more confidence one should have in the ability of that equation to perform reliably under a variety of forest conditions.

Table C1. Number of observations used in the development of the equations for Central States TWIGS.

Species Group	Uses Equations for This Group	Number of Observations
1 E. redcedar	E. redcedar	190
2 Shortleaf pine	Shortleaf pine	1,600
3 Virginia	Shortleaf pine (Group 2)	--
4 Other pines	Shortleaf pine (Group 2)	--
5 (not used)		
6 Walnut	Walnut	260
7 Tupelo	Tupelo	230
8 Select hickory	Select hickory	2,500
9 Other hickories	Select hickory (Group 8)	--
10 Beech	Other upland hdwds (Group 29)	--
11 Black ash	White & green ash (Group 19)	--
12 Cottonwood	Other lowland hdwds (Group 30)	--
13 Soft maple	Soft maple	350
14 Cherry	Other upland hdwds (Group 29)	--
15 Elm	Elm	550
16 Yellow poplar	Yellow poplar	130
17 Basswood	Other upland hdwds (group 29)	--
18 Hard maple	Hard maple	330
19 White & green ash	White & green ash	430
20 White oak	White oak	3,770
21 Red oak	Red oak	1,040
22 Black oak	Black oak	3,560
23 Scarlet oak	Scarlet oak	1,100
24 Blackjack oak	Blackjack oak	570
25 Chinkapin oak	Chinkapin oak	290
26 Post oak	Post oak	2,230
27 Chestnut oak	Chestnut oak	190
28 Pin oak	Pin oak	590
29 Other upland hdwds	Other upland hdwds	460
30 Other lowland hdwds	Other lowland hdwds	340
31 Noncommercial spp.	Noncommercial spp.	510

Table C2. Number of observations used in the development of the equations for Lake States TWIGS.

Species Group	Uses Equations for This Group	Number of Observations
1 Jack pine	Jack pine	664 - 8,934
2 Red pine	Red pine	390 - 39,998
3 White pine	White pine	538 - 2,394
4 White spruce	White spruce	227 - 3,548
5 Balsam fir	Balsam fir	771 - 17,169
6 Black spruce	Black spruce	316 - 13,212
7 Tamarack	Tamarack	61 - 2,673
8 N. white-cedar	N. white-cedar	813 - 2,782
9 Hemlock	Hemlock	140 - 1,447
10 Other softwoods	various groups	--
11 Black ash	Black ash	174 - 912
12 Cottonwood	Red maple (Group 14)	--
13 Silver maple	Red maple (Group 14)	--
14 Red maple	Red maple	937 - 3,860
15 Elm	Elm	344 - 4,337
16 Yellow birch	Yellow birch	343 - 1,129
17 Basswood	Basswood	813 - 4,056
18 Sugar maple	Sugar maple	2,251 - 9,383
19 White ash	White ash	148 - 2,818
20 White oak	White oak	480 - 1,666
21 N. red oak	N. red oak	1,158 - 3,378
22 Other red oak	Other red oak	80 - 3,021
23 Hickory	Hickory	114 - 3,573
24 Bigtooth aspen	Bigtooth aspen	94 - 1,426
25 Quaking aspen	Quaking aspen	2,124 - 6,892
26 Paper birch	Paper birch	748 - 2,364
27 (not used)		
28 (not used)		
29 (not used)		
30 Other hardwoods	Other hardwoods	190 - 219
31 Noncommercial spp.	Noncommercial spp.	175

APPENDIX D

VALIDATION TABLES

Lake States TWIGS Validation

Table D1. Summary of mean d.b.h. errors.

Table D2. Summary of mean basal area errors.

Table D3. Predicted and observed tree mortality rates.

Central States TWIGS Validation

Table D4. Summary of mean error in d.b.h. growth.

Table D5. Summary of mean error in basal area growth.

Table D6. Predicted and observed plot change (d.b.h., number of trees, basal area).

Table D7. Predicted and observed tree mortality rates.

Table Di.--Summary of the mean d.b.h. errors (inches) by Lake States species in 10 years using the STEMS85 model. The number of trees appears in parentheses. Positive values are overpredictions.

Species	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	-.11	(1,813)	-.19	(1,334)	-.12	(66)	-.18	(52)	.16	(182)	.17	(179)
Red pine	-.16	(1,374)	-.18	(879)	-.28	(64)	-.13	(69)	-.34	(135)	.08	(227)
White pine	-.04	(310)	-.20	(139)	.05	(36)	-.16	(36)	.09	(74)	.52	(25)
White spruce	.19	(171)	-.11	(64)	1.16	(14)	.37	(54)	.09	(39)	--	
Balsam fir	-.19	(693)	-.25	(326)	-.17	(150)	-.09	(125)	-.15	(89)	.15	(3)
Black spruce	-.29	(769)	-.29	(614)	-.26	(29)	-.19	(42)	-.36	(82)	-.19	(2)
Tamarack	.07	(334)	.12	(278)	-.17	(27)	-.27	(21)	-.05	(7)	.78	(1)
N. white-cedar	-.05	(916)	.12	(333)	-.03	(107)	-.01	(191)	-.02	(232)	.16	(53)
Hemlock	.11	(306)	--		.27	(50)	-.05	(122)	.19	(119)	.25	(15)
Black ash	.02	(189)	-.03	(51)	.16	(51)	.00	(35)	.03	(8)	-.09	(44)
Red maple	-.12	(798)	-.24	(68)	-.03	(191)	-.09	(64)	-.18	(258)	-.09	(217)
Elm	-.22	(194)	--		-.16	(48)	-.33	(126)	.08	(8)	.52	(12)
Yellow birch	-.09	(270)	.71	(2)	-.08	(92)	-.03	(78)	-.17	(83)	-.08	(15)
Basswood	.11	(274)	--		.01	(86)	.07	(150)	-.22	(5)	.62	(33)
Sugar maple	.01	(878)	--		.08	(293)	-.09	(354)	-.05	(164)	.34	(67)
White ash	-.04	(61)	--		-.19	(18)	-.43	(12)	--		.20	(31)
White oak	.21	(255)	--		--		--		--		.21	(255)
Northern red oak	.01	(258)	-.51	(3)	.08	(119)	-.19	(25)	-.23	(24)	.06	(87)
Northern pin oak	.14	(286)	--		.40	(4)	--		--		.13	(282)
Bigtooth aspen	.10	(227)	.45	(36)	-.11	(64)	-.14	(30)	-.05	(37)	.32	(60)
Quaking aspen	.08	(933)	.10	(388)	-.15	(134)	.04	(237)	.23	(118)	.25	(56)
Paper birch	.03	(1,102)	.02	(752)	-.19	(101)	-.32	(123)	.05	(96)	.01	(30)
All	-.06	(12,696)	-.12	(5,267)	-.03	(1,753)	-.08	(1,992)	-.06	(1,897)	.15	(1,787)

Includes all species on the property

Table D2.--Summary of the mean basal area errors (ft^2/ac) by Lake States species in 10 years using the STEMS85 model. The number of plots appears in parentheses. Positive values are overpredictions.

Forest type	All	Cloquet	Chequamegon	Nicolet	Hiawatha	Manistee
Jack pine	-2.5 (127)	-5.9 (79)	1.5 (7)	2.6 (6)	4.0 (20)	2.1 (15)
Red pine	-2.5 (85)	-3.6 (49)	2.8 (6)	-4.7 (4)	-9.1 (11)	4.2 (15)
White pine	-2.4 (13)	3.9 (6)	-2.7 (2)	-14.3 (2)	-6.6 (3)	--
White spruce	-3.1 (10)	5.9 (4)	-2.4 (1)	3.6 (4)	-4.4 (1)	--
Balsam fir	5.3 (51)	5.9 (23)	1.1 (14)	2.9 (8)	16.6 (6)	--
Black spruce	-4.3 (40)	-6.4 (29)	-2.5 (2)	11.3 (3)	-2.9 (6)	--
Tamarack	.0 (23)	1.7 (19)	-6.6 (2)	-10.2 (2)	--	--
N. white-cedar	-.7 (47)	1.7 (14)	.6 (8)	-4.0 (9)	-4.8 (14)	19.9 (20)
Hemlock	-12.5 (7)	--	--	-11.8 (4)	-13.4 (3)	--
Lowland hdwds.	16.4 (30)	4.4 (3)	18.2 (5)	3.1 (2)	-11.7 (1)	20.7 (19)
N. hardwoods	1.6 (135)	--	2.8 (40)	-1.2 (49)	-3.1 (28)	14.0 (18)
White oak	3.3 (15)	--	--	--	--	3.3 (15)
N. red oak	.6 (15)	--	-.7 (4)	-8.8 (1)	-8.7 (2)	4.7 (8)
Oak-pine	1.4 (10)	--	--	--	-21.3 (1)	3.9 (9)
Oak-hickory	.7 (35)	--	6.8 (1)	--	--	.5 (34)
Aspen	4.0 (121)	7.0 (30)	2.0 (23)	1.4 (42)	3.1 (14)	10.8 (12)
Paper birch	.7 (58)	1.0 (36)	1.1 (8)	-5.4 (9)	9.3 (4)	7.8 (1)
All	.9 (822)	-1.1 (292)	2.3 (123)	-.8 (145)	-1.1 (114)	7.1 (148)

Table D3.--Predicted and observed annual tree mortality rates by Lake States species for all validation properties using STEMS 85.

Species	No. of trees	Annual tree mortality rate	
		Predicted	Observed
		(Percent)	
Jack pine	2,336	1.6	1.8
Red pine	1,397	.1	.3
White pine	363	.1	1.7
White spruce	187	1.0	.6
Balsam fir	1,092	1.1	2.0
Black spruce	1,024	2.7	1.4
Tamarack	370	1.3	.7
N. white-cedar	987	.4	.8
Hemlock	323	.5	.6
Black ash	254	1.5	2.0
Red maple	852	1.8	1.4
Elm	293	3.0	4.1
Yellow birch	321	1.1	2.0
Basswood	303	2.0	1.2
Sugar maple	946	1.3	1.7
White ash	65	1.7	2.2
White oak	274	.1	1.9
N. red oak	273	4.2	1.5
N. pin oak	312	5.1	2.6
Bigtooth aspen	270	2.3	1.6
Quaking aspen	1,468	1.9	3.3
Paper birch	1,191	.4	.9
All[1]	15,240	1.4	1.6

[1] Includes all species on the property

Table D4.--Mean error in predicted 10-year tree diameter growth (in inches) by species group and diameter class for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group	Diameter class (inches)															
	1.0-4.9		5.0-8.9		9.0-10.9		11.0-14.9		15.0-20.9		21.0-24.9		25+		All classes	
Name	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.
E. redcedar	-.05	(126)	.10	(123)	.10	(20)	.22	(16)	-.10	(1)	0	(0)	0	(0)	.04	(286)
Shortleaf pine	-.02	(172)	.13	(1345)	.09	(390)	.01	(235)	-.20	(34)	0	(0)	0	(0)	.09	(2176)
Soft maple	.48	(76)	.55	(101)	.63	(75)	.46	(143)	.07	(100)	-.12	(23)	-.71	(19)	.36	(537)
Hard maple	.15	(108)	.13	(144)	-.18	(294)	-.19	(565)	-.27	(419)	-.19	(85)	-.47	(21)	-.16	(1636)
Hickory	.01	(952)	.07	(1538)	.06	(609)	-.09	(811)	-.36	(316)	-.86	(24)	-1.21	(8)	-.01	(4258)
Ash	.14	(145)	.25	(231)	.07	(163)	-.09	(279)	-.39	(138)	-.59	(26)	-.89	(8)	-.01	(990)
Walnut	-.02	(55)	.10	(165)	-.20	(95)	.01	(182)	-.18	(70)	-.43	(9)	-2.60	(1)	-.03	(577)
Tupelo	.05	(93)	.06	(50)	.09	(36)	.03	(90)	-.07	(62)	-.25	(11)	-.59	(5)	.01	(347)
White oak	.17	(636)	.02	(1914)	.04	(835)	.01	(1418)	-.12	(762)	-.15	(146)	-.36	(100)	.01	(5811)
Scarlet oak	.23	(170)	.18	(753)	.20	(273)	.22	(268)	.02	(128)	-.43	(21)	-1.38	(11)	.16	(1624)
Blackjack oak	-.02	(164)	.11	(297)	.05	(121)	.06	(154)	.06	(40)	-.47	(3)	0	(0)	.06	(779)
Chinkapin oak	-.02	(50)	.03	(229)	.06	(61)	-.03	(84)	-.29	(38)	-.62	(14)	-1.55	(5)	-.04	(481)
Red oak	.14	(90)	.16(	(448)	.11	(246)	-.06	(434)	-.13	(456)	-.33	(125)	-.73	(49)	-.03	(1848)
Post oak	.01	(626)	-.00	(1112)	.03	(450)	.07	(655)	.02	(312)	-.17	(63)	-.27	(13)	.02	(3231)
Black oak	.25	(534)	.07	(1833)	.06	(786)	.13	(1081)	-.05	(685)	-.15	(137)	-.37	(52)	.07	(5108)
Oth. upland oaks	-.02	(11)	-.17	(43)	-.16	(27)	-.11	(57)	-.32	(31)	-.94	(6)	-.80	(8)	-.22	(183)
Oth. lowland oaks	-.00	(57)	.34	(97)	.30	(57)	.19	(97)	.12	(100)	.38	(22)	-.22	(22)	.18	(452)
Elm	.07	(256)	.24	(321)	.07	(150)	-.04	(225)	-.03	(110)	-.22	(26)	-.59	(11)	.08	(1099)
Oth. upland hdwds	.22	(225)	.31	(124)	.25	(229)	.31	(425)	.27	(331)	.37	(81)	.20	(53)	.28	(1468)
Oth. lowland hdwds	-.47	(38)	.04	(97)	.20	(135)	.24	(274)	.13	(344)	-.23	(77)	-.27	(60)	.09	(1025)
Noncommercial spp.	.11	(509)	.37	(119)	.14	(26)	-1.25	(13)	-.41	(5)	0	(0)	0	(0)	.12	(672)
Yellow poplar	.20	(2)	-.53	(13)	-.20	(2)	-.23	(28)	-.22	(12)	.95	(2)	-.28	(2)	-.23	(61)
TOTAL	.10	(5095)	.09	(11097)	.07	(5080)	.04	(7534)	-.08	(4494)	-.18	(901)	-.42	(448)	.04	(34649)

Table D5.--Error in predicted 10-year tree basal area growth as a percent of initial tree basal area by species group and diameter class for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group	Diameter class (inches)															
	1.0-4.9		5.0-8.9		9.0-10.9		11.0-14.9		15.0-20.9		21.0-24.9		25+		All classes	
Name	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.
E. redcedar	-3.7	(126)	3.1	(123)	1.8	(20)	4.0	(16)	-1.2	(1)	0	(0)	0	(0)	.1	(286)
Shortleaf pine	-7.1	(172)	3.9	(1345)	1.5	(390)	.2	(235)	-2.8	(34)	0	(0)	0	(0)	2.1	(2176)
Soft maple	67.2	(76)	14.6	(101)	13.6	(75)	8.1	(143)	-.1	(100)	-1.9	(23)	-5.8	(19)	16.0	(537)
Hard maple	14.3	(108)	3.9	(144)	-4.9	(294)	-3.8	(565)	-3.6	(419)	-2.0	(85)	-3.8	(21)	-2.0	(1636)
Hickory	.7	(952)	2.0	(1538)	1.2	(609)	-1.8	(811)	-4.7	(316)	-8.1	(24)	-8.9	(8)	.3	(4258)
Ash	6.5	(145)	7.4	(231)	.7	(163)	-1.7	(279)	-5.4	(138)	-5.9	(26)	-7.1	(8)	1.4	(990)
Walnut	-14.6	(55)	1.8	(165)	-5.8	(95)	-.2	(182)	-2.5	(70)	-4.3	(9)	-19.7	(1)	-2.3	(577)
Tupelo	14.4	(93)	1.7	(50)	1.7	(36)	.4	(90)	-.9	(62)	-2.4	(11)	-4.7	(5)	4.1	(347)
White oak	21.2	(636)	-.1	(1914)	.6	(835)	.0	(1418)	-1.6	(762)	-1.6	(146)	-2.6	(100)	2.1	(5811)
Scarlet oak	32.5	(170)	5.8	(753)	4.3	(273)	3.9	(268)	.2	(128)	-4.1	(21)	-10.7	(11)	7.3	(1624)
Blackjack oak	-.1	(164)	3.3	(297)	.8	(121)	.8	(154)	.8	(40)	-4.4	(3)	0	(0)	1.6	(779)
Chinkapin oak	-7.1	(50)	.7	(229)	.9	(61)	-.4	(84)	-3.7	(38)	-5.9	(14)	-11.0	(5)	-.9	(481)
Red oak	18.2	(90)	5.3	(448)	1.9	(246)	-1.6	(434)	-1.9	(456)	-3.3	(125)	-5.7	(49)	1.2	(1848)
Post oak	-4.9	(626)	-.5	(1112)	.3	(450)	1.0	(655)	.1	(312)	-1.6	(63)	-2.0	(13)	-.9	(3231)
Black oak	40.7	(534)	1.8	(1833)	1.0	(786)	2.0	(1081)	-.8	(685)	-1.5	(137)	-2.9	(52)	5.3	(5108)
Other upland oaks	-8.4	(11)	-5.9	(43)	-3.8	(27)	-2.4	(57)	-4.2	(31)	-8.9	(6)	-5.9	(8)	-4.5	(183)
Other lowland oaks	-20.8	(57)	10.6	(97)	6.3	(57)	3.1	(97)	1.3	(100)	3.5	(22)	-1.5	(22)	1.5	(452)
Elm	3.3	(256)	6.8	(321)	.7	(150)	-1.4	(225)	-.8	(110)	-2.3	(26)	-4.0	(11)	2.4	(1099)
Oth. upland hdwds	21.2	(225)	10.1	(124)	4.9	(229)	4.9	(425)	3.2	(331)	3.5	(81)	1.6	(53)	7.3	(1468)
Oth. lowland hdwds	-194.8	(38)	-4.9	(97)	3.4	(135)	3.1	(274)	1.4	(344)	-2.7	(77)	-1.7	(60)	-6.2	(1025)
Noncommercial spp.	3.5	(509)	13.2	(119)	2.6	(26)	-24.0	(13)	-7.0	(5)	0	(0)	0	(0)	4.5	(672)
Yellow poplar	58.0	(2)	-23.1	(13)	-5.1	(2)	-5.3	(28)	-4.1	(12)	9.4	(2)	-1.6	(2)	-6.2	(61)
TOTAL	8.8	(5095)	2.6	(11097)	1.1	(5080)	.4	(7534)	-1.2	(4494)	-1.9	(901)	-3.1	(448)	2.1	(34649)

Table D6. Comparison of observed and predicted plot change using Central States TWIGS.

Category	Tree Diameter[a] (inches/tree)		Number of Trees[b] (number/acre)		Basal Area[b] (sq. ft./acre)	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
Initial	9.1(5.3)	9.0(5.1)	671(860)	649(888)	66(26)	61(25)
Observed (after 10 years of growth)	10.4(5.6)	10.2(5.4)	453(608)	428(563)	66(34)	64(35)
Predicted (from 10 years of simulation)	10.4(5.5)	10.2(5.3)	416(459)	403(462)	69(33)	66(33)
Difference	.052(.72)	.025(.73)	-37(284)	-25(248)	3(13)	2(14)

[a] Means with standard deviations in parentheses for 7697 calibration trees and 7510 validation trees.

[b] Means with standard deviations in parentheses for 577 calibration plots and 566 validation plots.

Calibration data is a subset of those data used to develop models and coefficients. Validation data is the 1/4 of plots reserved prior to model development.

Table D7.--Comparison of observed and predicted mortality rates by species group for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group Name	No. of trees	Annual tree mortality		
		Predicted	Observed	Difference
- - -		- - - - - - - (Percent) - - - - -		
E. redcedar	301	2.1619	2.2698	-.1079
Shortleaf pine	2298	1.7066	1.6901	.0165
Soft maple	645	2.7740	1.8495	.9245
Hard maple	1701	1.7677	1.7196	.0482
Hickory	4653	2.3397	2.1220	.2177
Ash	1121	4.3729	4.4429	-.0701
Walnut	662	2.9315	3.1595	-.2281
Tupelo	377	1.3030	.8211	.4819
White oak	6180	2.1984	1.9390	.2595
Scarlet oak	1862	4.8290	3.4251	1.4039
Blackjack oak	1059	5.8929	5.6654	.2275
Chinkapin oak	518	3.4640	1.4867	1.9773
Red oak	2003	1.8909	3.2118	-1.3209
Post oak	3639	2.6904	2.8299	-.1395
Black oak	5722	2.9793	3.4726	-.4933
Other upland oaks	197	3.2301	2.6135	.6166
Other lowland oaks	524	3.3416	2.3492	.9924
Elm	2204	4.6019	3.7001	.9017
Other upland hdwds.	1732	6.7222	6.9149	-.1927
Other lowland hdwds.	1182	2.9285	4.7090	-1.7804
Noncommercial spp.	967	3.7874	4.2246	-.4372
Yellow poplar	63	1.8191	.1771	1.6420
TOTAL	39610	3.2226	3.1790	.0436

APPENDIX E

LAKE AND CENTRAL STATES TWIGS

WEIGHT AND VOLUME EQUATIONS AND COEFFICIENTS

TWIGS calculates the weight and volume of each tree individually using generalized equations with species specific coefficients. The individual tree weights and volumes are summed by species and product class, then presented in the Volume Report (fig. 20). The product class limits are diagrammed in figure 3.

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LAKE STATES TWIGS

ACCEPTABLE TREE CLASS VOLUME

The following general equation is used for cubic foot and board foot volume of acceptable (tree class 20) trees. This net merchantable tree volume equation was developed for the Upper Peninsula of Michigan (Raile *et al.*, 1982). Total net cubic foot volume of acceptable trees is computed using equation E1 and the coefficients in Table E1. Net board foot volume is computed using equation E1 along with the coefficients in Table E2. Net cubic foot saw log volume is calculated using equation E1 and the coefficients in Table E3.

$$V_{20} = a\ SI^{b}[1 - e^{-c\ D}]^{d} \qquad [E1]$$

Where:

V_{20} = net volume of an acceptable tree (tree class 20);

SI = species specific site index (feet at age 50);
D = current tree diameter (d.b.h. in inches); and
a,b,c,d = species specific equation coefficients from Table E1, Table E2, or Table E3.

Table E1. Coefficients to calculate total net cubic foot volume for acceptable trees in Lake States TWIGS, equation E1.

Lake States				
Species Group	a	b	c	d
1	43.	.249415	.0633760	3.3981
2	208.	.101513	.0434772	3.2805
3	7116254.	.246024	.0005161	2.7799
4	794.	.086980	.0246854	3.0336
5	5907203.	.212635	.0005561	2.7161
6	23975168.	.148390	.0003563	2.6941
7	44.	.000000	.1601605	5.6228
8	829654.	.055217	.0006650	2.3394
9	7702181.	.305867	.0002745	2.5641
10	43.	.249415	.0633760	3.3981
11	26920.	.140461	.0031300	2.4281
12	7257393.	1.016275	.0001747	2.8370
13	84.	.138548	.0576398	3.1838
14	84.	.138548	.0576398	3.1838
15	140.	.438708	.0191369	2.5388
16	4117942.	.291399	.0002105	2.3009
17	221.	.121958	.0359248	2.9440
18	500.	.007421	.0282525	2.7577
19	26920.	.140461	.0031300	2.4281
20	226.	.060183	.0407774	3.0682
21	226.	.060183	.0407774	3.0682
22	226.	.060183	.0407774	3.0682
23	14.	.338689	.1181669	4.4888
24	158.	.213605	.0315426	2.7168
25	158.	.213605	.0315426	2.7168
26	7256.	.109934	.0036266	2.0926
27	14.	.338689	.1181669	4.4888
28	14.	.338689	.1181669	4.4888
29	14.	.338689	.1181669	4.4888
30	14.	.338689	.1181669	4.4888
31	14.	.338689	.1181669	4.4888

Table E2. Coefficients to calculate net board foot volume (International 1/4-inch rule) for acceptable trees in Lake States TWIGS, equation E1.

	Lake States			
Species Group	a	b	c	d
1	169.	.39511	.0512433	3.196
2	2969.	.25519	.0179006	2.761
3	36276656.	.14236	.0008274	2.973
4	35253.	.00000	.0110881	2.866
5	27980.	.33410	.0096929	3.261
6	28937072.	.06307	.0014004	3.165
7	63.	.22695	.3284979	26.891
8	5756055.	.00000	.0007904	2.463
9	2586729.	.05437	.0013930	2.636
10	169.	.39511	.0512433	3.196
11	10925208.	.02244	.0008219	2.564
12	15938236.	.75718	.0002925	2.740
13	120.	.27194	.1734226	11.676
14	120.	.27194	.1734226	11.676
15	1211353.	.57651	.0001273	1.834
16	400.	.31603	.0458705	3.418
17	201.	.26549	.1115628	6.420
18	712.	.00000	.0995210	5.866
19	10925208.	.02244	.0008219	2.564
20	1007.	.00000	.0688690	4.382
21	1007.	.00000	.0688690	4.382
22	1007.	.00000	.0688690	4.382
23	8070.	.63809	.0003951	1.346
24	393.	.19532	.0640377	3.681
25	393.	.19532	.0640377	3.681
26	9103704.	.00000	.0001737	1.882
27	8070.	.63809	.0003951	1.346
28	8070.	.63809	.0003951	1.346
29	8070.	.63809	.0003951	1.346
30	8070.	.63809	.0003951	1.346
31	8070.	.63809	.0003951	1.346

Table E3. Coefficients to calculate net cubic foot saw log volume for acceptable trees in Lake States TWIGS, equation E1.

	Lake States			
Species Group	a	b	c	d
1	9.	.53396	.0854854	4.216
2	173.	.13296	.0419059	3.166
3	27973504.	.15545	.0003431	2.776
4	765.	.02644	.0277262	3.168
5	350.	.39522	.0244354	3.503
6	13205354.	.02868	.0008994	3.047
7	12.	.22306	.2933120	20.224
8	329.	.04549	.0318424	3.132
9	13742.	.09324	.0050556	2.643
10	9.	.53396	.0854854	4.216
11	2361292.	.08194	.0004847	2.400
12	9227411.	.62755	.0001703	2.606
13	34.	.18168	.1402485	8.552
14	34.	.18168	.1402485	8.552
15	315786.	.63848	.0000997	1.886
16	233.	.18111	.0285956	2.971
17	33.	.23508	.1324740	8.230
18	116.	.00000	.0971358	5.752
19	2361292.	.08194	.0004847	2.400
20	92.	.00000	.1129755	6.721
21	92.	.00000	.1129755	6.721
22	92.	.00000	.1129755	6.721
23	2361292.	.08194	.0004847	2.400
24	36.	.25513	.0895516	4.727
25	36.	.25513	.0895516	4.727
26	36.	.25513	.0895516	4.727
27	116.	.00000	.0971358	5.752
28	116.	.00000	.0971358	5.752
29	116.	.00000	.0971358	5.752
30	116.	.00000	.0971358	5.752
31	116.	.00000	.0971358	5.752

UNDESIRABLE TREE CLASS VOLUME

The net cubic foot volume of undesirable (tree class 30) trees is determined by taking a proportion of the total acceptable tree class volume.

$$V_{30} = a\ V_{20} \qquad [E2]$$

Where:

V_{30} = net cubic foot volume of an undesirable tree (tree class 30);
V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1; and
a = species specific value from Table E4.

Table E4. Values to calculate net cubic foot volume for undesirable trees in Lake States TWIGS (Hahn 1984), equation E2.

Lake States	
Species Group	a
1	.822
2	.888
3	.834
4	.883
5	.889
6	.879
7	.832
8	.828
9	.751
10	.780
11	.798
12	.803
13	.832
14	.832
15	.868
16	.803
17	.860
18	.823
19	.822
20	.860
21	.856
22	.893
23	.848
24	.793
25	.782
26	.857
27	.000
28	.000
29	.000
30	.790
31	.832

RESIDUE WEIGHT

Calculating weight for each tree in the residue product class is a multistep process that incorporates coefficients and multipliers from many sources. The process is outlined here with reference to sources.

Residue includes the tops and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees, all trees less than 5 inches d.b.h., and cull trees (tree class 40).

STEP 1 Calculate weight of trees less than 5 inches d.b.h. (equation developed by G. K. Raile using data from Young *et al*. 1976).

$$WT_{lt5} = \frac{.8(4.89\ D^{2.432})}{2000} \qquad [E3]$$

Where:

WT_{lt5} = weight of a tree less than 5 inches d.b.h. in tons; and

D = current tree diameter (d.b.h. in inches).

STEP 2 Calculate bark adjustment factors for trees with a d.b.h. 5 inches or greater (Raile, 1986).

$$Badj = a + b(D) \qquad [E4]$$

Where:
Badj = bark adjustment factor;
D = current tree diameter (d.b.h. in inches); and
a,b = species specific equation coefficients from Table E5.

Table E5. Coefficients to calculate bark adjustment factors in Lake States TWIGS, equation E4.

Lake States		
Species Group	a	b
1	0.8677	0.00854
2	1.0179	-.00550
3	0.9588	0.00000
4	1.0552	0.00000
5	0.9992	0.00000
6	0.9577	0.00504
7	1.0552	0.00000
8	1.0343	0.00000
9	0.8468	0.00000
10	0.8677	0.00854
11	0.9844	0.00000
12	0.9739	0.00000
13	1.0219	0.00000
14	1.0219	0.00000
15	0.9895	0.00000
16	1.0241	0.00000
17	0.9707	0.00000
18	1.0442	-.00164
19	0.9611	0.00000
20	0.9348	0.00000
21	0.9658	0.00191
22	0.9720	0.00000
23	0.9611	0.00000
24	0.9151	0.00365
25	0.9151	0.00365
26	0.9821	0.00205
27	1.0000	0.00000
28	1.0000	0.00000
29	1.0000	0.00000
30	1.0000	0.00000
31	1.0000	0.00000

STEP 3 Calculate weight of bark on bole (Raile 1986).

$$WT_{bark} = \frac{V_{20}\ (1.646 - Badj)\ 37}{2000} \qquad [E5]$$

Where:

WT_{bark} = weight of bark on bole in tons;

V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1; and

Badj = bark adjustment factor from equation E4.

STEP 4 Convert bole volume to bole weight (Raile 1986).

$$WT_{bole} = \frac{V_{20}\ (WT_{sp})\ Badj}{2000} \qquad [E6]$$

Where:

WT_{bole} = weight of bole in tons;

V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1;

Badj = bark adjustment factor from equation E4; and

WT_{sp} = wood density in pounds per cubic foot for each species from Table E6.

Table E6. Wood density in pounds per cubic foot for species in Lake States TWIGS (Markwardt 1930), equations E6 and E10.

Lake States	
Species Group	WT_{sp}
1	50.0
2	42.0
3	36.0
4	35.0
5	45.0
6	32.0
7	47.0
8	28.0
9	43.0
10	43.0
11	49.0
12	40.0
13	48.0
14	48.0
15	50.0
16	57.0
17	43.0
18	56.0
19	49.0
20	62.0
21	62.0
22	63.0
23	63.0
24	43.0
25	43.0
26	50.0
27	52.0
28	52.0
29	52.0
30	50.0
31	50.0

STEP 5 Calculate weight of top and limbs for a tree equal to or greater than 5 inches d.b.h. (Raile 1986).

$$WT_{top} = .45(WT_{bole} + WT_{bark}) \qquad [E7]$$

Where:

WT_{top} = weight of top and limbs in tons;
WT_{bole} = weight of bole in tons from equation E6; and
WT_{bark} = weight of bark in tons from equation E5.

STEP 6 Calculate total weight of a cull tree (tree class 40).

$$WT_{cull} = (WT_{top} + WT_{bole} + WT_{bark})b \qquad [E8]$$

Where:

WT_{cull} = total weight of a cull tree in tons;

WT_{top} = weight of top and limbs in tons from equation E7;

WT_{bole} = weight of bole in tons from equation E6;

WT_{bark} = weight of bark in tons from equation E5; and

b = species specific equation coefficients from Table E7.

Table E7. Coefficients to calculate total weight of cull trees in Lake States TWIGS (Hahn, 1984), equation E8.

Lake States	
Species Group	b
1	.369
2	.257
3	.354
4	.440
5	.366
6	.423
7	.416
8	.388
9	.281
10	.478
11	.328
12	.294
13	.377
14	.377
15	.360
16	.360
17	.367
18	.383
19	.378
20	.344
21	.364
22	.335
23	.343
24	.403
25	.382
26	.351
27	.000
28	.000
29	.000
30	.358
31	.358

STEP 7 Calculate total residue by summing values for all trees. (Each tree contributes to only one category on the right-hand side of the equation.)

$$\text{Residue Weight} = WT_{lt5} + WT_{top} + WT_{cull} \qquad [E9]$$

Where:

Residue weight = tons of residue per acre;

WT_{lt5} = weight in tons of trees less than 5 inches d.b.h. from equation E3;

WT_{top} = weight in tons of top and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees from equation E7; and

WT_{cull} = weight in tons of cull trees (tree class 40) from equation E8.

RESIDUE VOLUME

Compute total cubic feet of residue by dividing total tons of residue by species specific equation coefficients from Table E6.

$$\text{Residue volume} = \frac{\text{residue weight (2000)}}{WT_{sp}} \qquad [E10]$$

Where:

Residue volume = cubic feet per acre;

Residue weight = tons per acre from equation E9; and

WT_{sp} = wood density in pounds per cubic foot for each species from Table E6.

CENTRAL STATES TWIGS

ACCEPTABLE AND UNDESIRABLE TREE CLASS VOLUME

The following equation was used for cubic foot and board foot volume of acceptable (tree class 20) trees and for cubic foot volume of undesirable (tree class 30) trees. This net volume equation was developed for Indiana (Smith and Weist 1982).

$$V = a\ SI^{b}[1 - e^{-c\ D^{d}}] \qquad [E11]$$

Where:

V = net volume;
SI = site index (feet at age 50);
D = current tree diameter (d.b.h. in inches); and
a,b,c,d = species specific equation coefficients in Tables E8-E11.

Table E8. Coefficients to calculate net cubic foot volume for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	24.3201	.8216	.000044	2.5616
2	32.7134	.3785	.000089	2.7986
3	32.7134	.3785	.000089	2.7986
4	32.7134	.3785	.000089	2.7986
5	.0000	.0000	.000000	.0000
6	65.4786	.0383	.000265	2.7537
7	15.8460	.5938	.000063	2.8574
8	24.3795	.5106	.000086	2.7597
9	24.3795	.5106	.000086	2.7597
10	16.7211	.5991	.000080	2.7109
11	168.5280	.0904	.000099	2.6121
12	16.7211	.5991	.000080	2.7109
13	948.9211	.0000	.000059	2.3163
14	16.7211	.5991	.000080	2.7109
15	341.7616	.0000	.000083	2.5673
16	16.7211	.5991	.000080	2.7109
17	16.7211	.5991	.000080	2.7109
18	948.9211	.0000	.000059	2.3163
19	168.5280	.0904	.000099	2.6121
20	21.1498	.5754	.000110	2.5942
21	126.1555	.2152	.000081	2.5973
22	126.1555	.2152	.000081	2.5973
23	126.1555	.2152	.000081	2.5973
24	126.1555	.2152	.000081	2.5973
25	21.1498	.5754	.000110	2.5942
26	21.1498	.5754	.000110	2.5942
27	16.7211	.5991	.000080	2.7109
28	16.7211	.5991	.000080	2.7109
29	16.7211	.5991	.000080	2.7109
30	16.7211	.5991	.000080	2.7109
31	16.7211	.5991	.000080	2.7109

Table E9. Coefficients to calculate net cubic foot saw-log volume for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	32.7134	.3785	.000089	2.7986
2	8.5339	.5167	.000231	2.7641
3	8.5339	.5167	.000231	2.7641
4	8.5339	.5167	.000231	2.7641
5	8.5339	.5167	.000231	2.7641
6	528.3431	.1433	.000030	2.4206
7	4.0386	.6312	.000064	3.1986
8	142.5035	.0034	.000116	2.6411
9	142.5035	.0034	.000116	2.6411
10	15.0211	.4755	.000087	2.8131
11	527.1757	.0000	.000078	2.2867
12	15.0211	.4755	.000087	2.8131
13	190.0165	.0000	.000199	2.3569
14	15.0211	.4755	.000087	2.8131
15	77.4351	.0922	.000154	2.6564
16	15.0211	.4755	.000087	2.8131
17	15.0211	.4755	.000087	2.8131
18	190.0165	.0000	.000199	2.3569
19	527.1757	.0000	.000078	2.2867
20	32.6541	.4767	.000084	2.6689
21	108.1743	.0818	.000175	2.4623
22	108.1743	.0818	.000175	2.4623
23	108.1743	.0818	.000175	2.4623
24	108.1743	.0818	.000175	2.4623
25	32.6541	.4767	.000084	2.6689
26	32.6541	.4767	.000084	2.6689
27	15.0211	.4755	.000087	2.8131
28	15.0211	.4755	.000087	2.8131
29	15.0211	.4755	.000087	2.8131
30	15.0211	.4755	.000087	2.8131
31	15.0211	.4755	.000087	2.8131

Table E10. Coefficients to calculate net board foot volume (International 1/4-inch rule) for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	68.6358	.6359	.000082	2.8486
2	68.6528	.9374	.000040	2.6643
3	68.6528	.9374	.000040	2.6643
4	68.6528	.9374	.000040	2.6643
5	68.6528	.9374	.000040	2.6643
6	68.6472	.5722	.000087	2.8488
7	178.1367	.3166	.000083	2.8811
8	1151.2737	.0000	.000077	2.7331
9	1151.2737	.0000	.000077	2.7331
10	164.5671	.4052	.000061	2.8766
11	68.6341	.7813	.000079	2.5203
12	164.5671	.4052	.000061	2.8766
13	68.6272	.5665	.000140	2.7006
14	164.5671	.4052	.000061	2.8766
15	693.5429	.0476	.000071	2.9203
16	164.5671	.4052	.000061	2.8766
17	164.5671	.4052	.000061	2.8766
18	68.6272	.5665	.000140	2.7006
19	68.6341	.7813	.000079	2.5203
20	103.7664	.6707	.000076	2.6670
21	871.4258	.0682	.000112	2.5879
22	871.4258	.0682	.000112	2.5879
23	871.4258	.0682	.000112	2.5879
24	871.4258	.0682	.000112	2.5879
25	103.7664	.6707	.000076	2.6670
26	103.7664	.6707	.000076	2.6670
27	164.5671	.4052	.000061	2.8766
28	164.5671	.4052	.000061	2.8766
29	164.5671	.4052	.000061	2.8766
30	164.5671	.4052	.000061	2.8766
31	164.5671	.4052	.000061	2.8766

Table E11. Coefficients to calculate net cubic foot volume for undesirable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	22.7769	.4240	.000057	2.9092
2	22.7769	.4240	.000057	2.9092
3	22.7769	.4240	.000057	2.9092
4	22.7769	.4240	.000057	2.9092
5	.00	.0000	.000000	.0000
6	57.1662	.4545	.000048	2.5027
7	57.1662	.4545	.000048	2.5027
8	18.6983	.4097	.000132	2.7085
9	18.6983	.4097	.000132	2.7085
10	57.1662	.4545	.000048	2.5027
11	5.0944	.6960	.000158	2.6118
12	57.1662	.4545	.000048	2.5027
13	72.0477	.0743	.000166	2.7068
14	57.1662	.4545	.000048	2.5027
15	25.5502	.1927	.000200	2.7686
16	57.1662	.4545	.000048	2.5027
17	57.1662	.4545	.000048	2.5027
18	72.0477	.0743	.000166	2.7068
19	5.0944	.6960	.000158	2.6118
20	104.1617	.0890	.000119	2.5916
21	21.1882	.6788	.000073	2.4026
22	21.1882	.6788	.000073	2.4026
23	21.1882	.6788	.000073	2.4026
24	21.1882	.6788	.000073	2.4026
25	104.1617	.0890	.000119	2.5916
26	104.1617	.0890	.000119	2.5916
27	57.1662	.4545	.000048	2.5027
28	57.1662	.4545	.000048	2.5027
29	57.1662	.4545	.000048	2.5027
30	57.1662	.4545	.000048	2.5027
31	57.1662	.4545	.000048	2.5027

RESIDUE WEIGHT

Residue includes the tops and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees, all trees less than 5 inches d.b.h., and cull trees (tree class 40).

Residue weight is calculated in three steps.

STEP 1 Calculate weight of tops and limbs of all tree classes and bole weight of cull trees (Raile and Jakes 1982).

$$WT_{tlc} = a\ D^{b} \qquad [E12]$$

Where:

WT_{tlc} = weight in green tons of tops and limbs for all tree classes and bole of cull trees;
D = current tree diameter (d.b.h. in inches); and
a,b = species specific equation coefficients from Table E12.

Table E12. Coefficients to calculate weight of tops, limbs, and cull trees in Central States TWIGS, equation E12.

	Central States					
Species Group	Tops and limbs Tree class 20		Boles Tree class 40		Tops and limbs Tree class 30 and 40	
	a	b	a	b	a	b
1	.0013360	1.8396	.0001840	2.7407	.0001480	2.7578
2	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
3	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
4	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
5	.0000000	.0000	.0000000	.0000	.0000000	.0000
6	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
7	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
8	.0019400	1.9741	.0002210	2.8099	.0001760	2.8005
9	.0019400	1.9741	.0002210	2.8099	.0001760	2.8005
10	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
11	.0002690	2.6291	.0001170	2.1310	.0009300	2.1301
12	.0001100	2.9053	.0004680	2.5535	.0003630	2.5537
13	.0004590	2.4164	.0011240	2.1090	.0001390	2.7753
14	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
15	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
16	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
17	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
18	.0003650	2.5440	.0007360	2.3281	.0005820	2.3264
19	.0002690	2.6291	.0001170	2.1310	.0009300	2.1301
20	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
21	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
22	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
23	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
24	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
25	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
26	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
27	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
28	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
29	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
30	.0001100	2.9053	.0004680	2.5535	.0003630	2.5537
31	.0004070	2.4564	.0004190	2.5684	.0003200	2.5687

STEP 2 Calculate weight of trees less than 5 inches d.b.h. (Equation developed by G. K. Raile using data from Young *et al*. 1976)

$$WT_{lt5} = \frac{.8(4.89D^{2.432})}{2000} \qquad [E3]$$

Where:

WT_{lt5} = weight in tons of a tree less than 5 inches d.b.h.; and

D = current tree diameter (d.b.h. in inches).

STEP 3 Calculate total residue by summing values for all trees.

$$\text{Residue weight} = \quad WT_{tlc} + \quad WT_{lt5} \qquad [E13]$$

Where:

Residue weight = tons of residue per acre;
WT_{tlc} = weight in tons of tops and limbs from all tree classes and bole of cull trees from equation E12; and
WT_{lt5} = weight in tons of trees less than 5 inches d.b.h. from equation E3.

RESIDUE VOLUME

Compute total cubic feet of residue by dividing total tons of residue by species specific equation coefficients in Table E13.

$$\text{Residue Volume} = \frac{\text{Residue weight (2000)}}{WT_{sp}} \qquad [E14]$$

Where:

Residue volume = cubic feet per acre;
Residue weight = tons per acre from equation E13; and
WT_{sp} = wood density in pounds per cubic foot for each species from Table E13.

Table E13. Wood density in pounds per cubic foot for species in Central States TWIGS (Markwardt 1930), equation E14.

Species Group	WT_{sp}
1	37.0
2	51.0
3	51.0
4	51.0
5	0.0
6	58.0
7	62.0
8	64.0
9	64.0
10	38.0
11	48.0
12	49.0
13	45.0
14	38.0
15	54.0
16	38.0
17	38.0
18	56.0
19	48.0
20	62.0
21	63.0
22	62.0
23	63.0
24	65.0
25	63.0
26	63.0
27	63.0
28	54.0
29	38.0
30	49.0
31	59.0

LAKE AND CENTRAL STATES TWIGS

LOG RULE CONVERSION FACTORS

The following log rule conversion factors were used to convert International 1/4" rule to Scribner or Doyle (Smith 1986).

Diameter Class	To Scribner (Lake States)		To Doyle (Central States)	
	Hardwood	Softwoods	Hardwoods	Softwoods
9.0-10.9"	.00	.80	.00	.50
11.0-12.9"	.73	.87	.45	.51
13.0-14.9"	.82	.98	.54	.62
15.0-16.9"	.88	1.04	.62	.65
17.0-18.9"	.93	1.08	.67	.78
19.0-20.9"	.98	1.12	.72	.82
21.0-22.9"	1.02	1.10	.77	.84
23.0-24.9"	1.06	1.10	.79	.91
25.0-26.9"	1.10	1.08	.82	1.00
27.0-28.9"	1.14	1.10	.89	.95
29.0-30.9"	1.15	1.09	.92	1.05
31.0-32.9"	1.19	1.11	.94	1.09
33.0+	1.23	1.09	.97	1.13

APPENDIX F

TREE LIST FORMAT

Although TREEGEN formats the input provided by the user for TWIGS, the users may find it more convenient in some cases to edit an existing tree list file than to create a new one with TREEGEN. This Appendix describes the format of a tree list file.

A tree list file consists of one header line of stand characteristics, two lines specifying species specific site indices, and one line for each individual tree entry:

```
Walt's Woods    mxdjack     1986       39       1       0       22
  61   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   1   1 105   4.0    .0   54.0   1  20
   2   1 105   5.0    .0  295.0   1  20
   3   1 105   6.0    .0   62.0   1  20
   4   1 105   7.0    .0   60.0   1  20
   5   1 105   8.0    .0   81.0   1  20
   6   1 105   9.0    .0   11.0   1  20
   7   1 105  10.0    .0   31.0   1  20
   8   1 105  11.0    .0    1.0   1  20
   9   1 105  12.0    .0    1.0   1  20
  10   3 125   3.0    .0   19.0   1  30
  11   3 125   5.0    .0    7.0   1  30
  12   3 125   7.0    .0    4.0   1  30
  13   2 125   3.0    .0   38.0   1  20
  14   2 125   6.0    .0   24.0   1  20
  15   2 125  11.0    .0    1.0   1  20
  16  25 746   3.0    .0   19.0   1  20
  17  25 746   5.0    .0   34.0   1  20
  18  25 746   6.0    .0   14.0   1  20
  19  25 746   7.0    .0    4.0   1  20
  20  25 746   8.0    .0   11.0   1  20
  21  25 746   9.0    .0    6.0   1  20
  22  25 746   6.0    .0    5.0   1  30
```

The HEADER LINE contains

a. Property name (optional), in columns 1-16 (Walt's Woods).
b. Stand name (optional), in columns 17-24 (mxdjack).
c. Year the stand was measured, in columns 25-32 (1986).
d. Stand age at the year the stand was measured, in columns 33-40 (39).
e. Species group used to measure site index, in columns 41-48 (1).
f. Red pine plantation denotation, in columns 49-56; Lake States TWIGS only (0, where: 0 = no, 1 = yes).
g. Number of tree list entries, in columns 57-64 (22).

The species specific SITE INDICES LINES contain a 4-column field for each of the 31 species groups. In the above tree list only the first field is used (SI=61).

Each INDIVIDUAL TREE entry includes

a. Sequential tree entry number (integer) not to exceed 500.
b. STEMS species groups code (integer). See Appendix A.
c. USFS species code (integer). See Appendix A.
d. Diameter at breast height (real number) in inches.
e. Crown ratio code (real number). See page .
f. Expansion factor (real number). See page .
g. Status (integer) where 1 = live, 2 = cut, 3 = dead. All trees on an initial tree list should have status = 1.
h. Tree class (integer) where 20 = acceptable, 30 = undesirable, and 40 = cull.

The format specification for the individual tree entries is (3I4, 2F6.1, F8.1, 2I4).

APPENDIX G

PRINTOUT FROM AN EXAMPLE TWIGS RUN

```
Welcome to the wonderful world of ---
 TTTTT  W    W   III   GGGG  SSSS        The
   T    W    W    I    G     S           Woodsman's
   T    W WW W    I    G GG  SSSS        Ideal
   T    WW  WW    I    G  G     S        Growth projection
   T    W    W   III   GGGG  SSSS        System

Lake States 3.0 (July 1987).

Microsoft FORTRAN for the IBM microcomputer

Written by: Kevin K. Nimerfro and Monique L. Belli
With direction from: Gary J. Brand, Nancy R. Walters,
                     Charles R. Blinn, Dietmar W. Rose



::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::  Tree List File is LSTLIST                                               ::
::                                                                          ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


  17 Trees will be read for property "CLOQUET", stand "COMP 284"
year= 1987, age= 56, site index for RED PINE= 55.0, plantation= 0

Seq    Stems   USFS     Stems                     Crown              Tree   Tree
num    code    code     grp name           Dbh    ratio   Trees/ac   status class
  1       2     125     RED PINE           5.0      .0        28.0     1     20
  2       2     125     RED PINE           6.0      .0        21.0     1     20
  3       2     125     RED PINE           7.0      .0        28.0     1     20
  4       2     125     RED PINE           8.0      .0        42.0     1     20
  5       2     125     RED PINE           9.0      .0        28.0     1     20
  6       2     125     RED PINE          10.0      .0        14.0     1     20
  7       2     125     RED PINE          11.0      .0        49.0     1     20
  8       2     125     RED PINE          12.0      .0        14.0     1     20
  9       2     125     RED PINE          13.0      .0        14.0     1     20
 10       1     105     JACK PINE          6.0      .0         7.0     1     20
 11       1     105     JACK PINE         10.0      .0        21.0     1     20
 12       1     105     JACK PINE         11.0      .0         7.0     1     20
 13      26     375     PAP.BIRCH          5.0      .0         7.0     1     20
 14      26     375     PAP.BIRCH          6.0      .0         7.0     1     20
 15      26     375     PAP.BIRCH          7.0      .0         7.0     1     20
 16      26     375     PAP.BIRCH          8.0      .0         7.0     1     20
 17       3     129     WHITE PINE         8.0      .0         7.0     1     20

 Tree list has  17 trees, tpa= 308.0, batot= 132.9, dbh=  8.6
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                              ::
::                        S T U M P A G E   R A T E S                           ::
::                                                                              ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


User has not yet supplied stumpage rates.


Default stumpage rates:

       Sawtimber     Poletimber    Residue
       $/1000 bdft   $/cord        $/100 cuft
       -----------   -----------   -----------

      $      29.00 $       6.00 $         .00




       ANALYSIS FOR STAND: COMP 284
       STAND AGE IN 1987 IS  56 YEARS


                        ECONOMIC ANALYSIS INPUTS

       NOMINAL DISCOUNT RATE                         7.00%
       GENERAL INFLATION RATE                        4.00%
       STUMPAGE PRICE INFLATION RATE                 1.20%
       BASE YEAR FOR THE ANALYSIS                    1987
       END YEAR FOR THE ANALYSIS                     2007


DIARY OF COST AND REVENUE ACTIVITIES:

          (ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY      NAME        YEAR(S)        COST      REVENUE   INFLATION RATE

_____  ____________  ___________  __________  __________  _____________
  1    Buy Land         1987         300.00         .00          .00
  2    Property Tax  1987-2007          .90         .00          .00
  3    Sale Prep.       1987          65.00         .00          .00
                        2007          65.00         .00          .00
  4    Sale Admin.      1987          22.00         .00          .00
                        2007          22.00         .00          .00
  5    Sell Land        2007            .00      300.00          .00
-----------------------------------------------------------------------
```

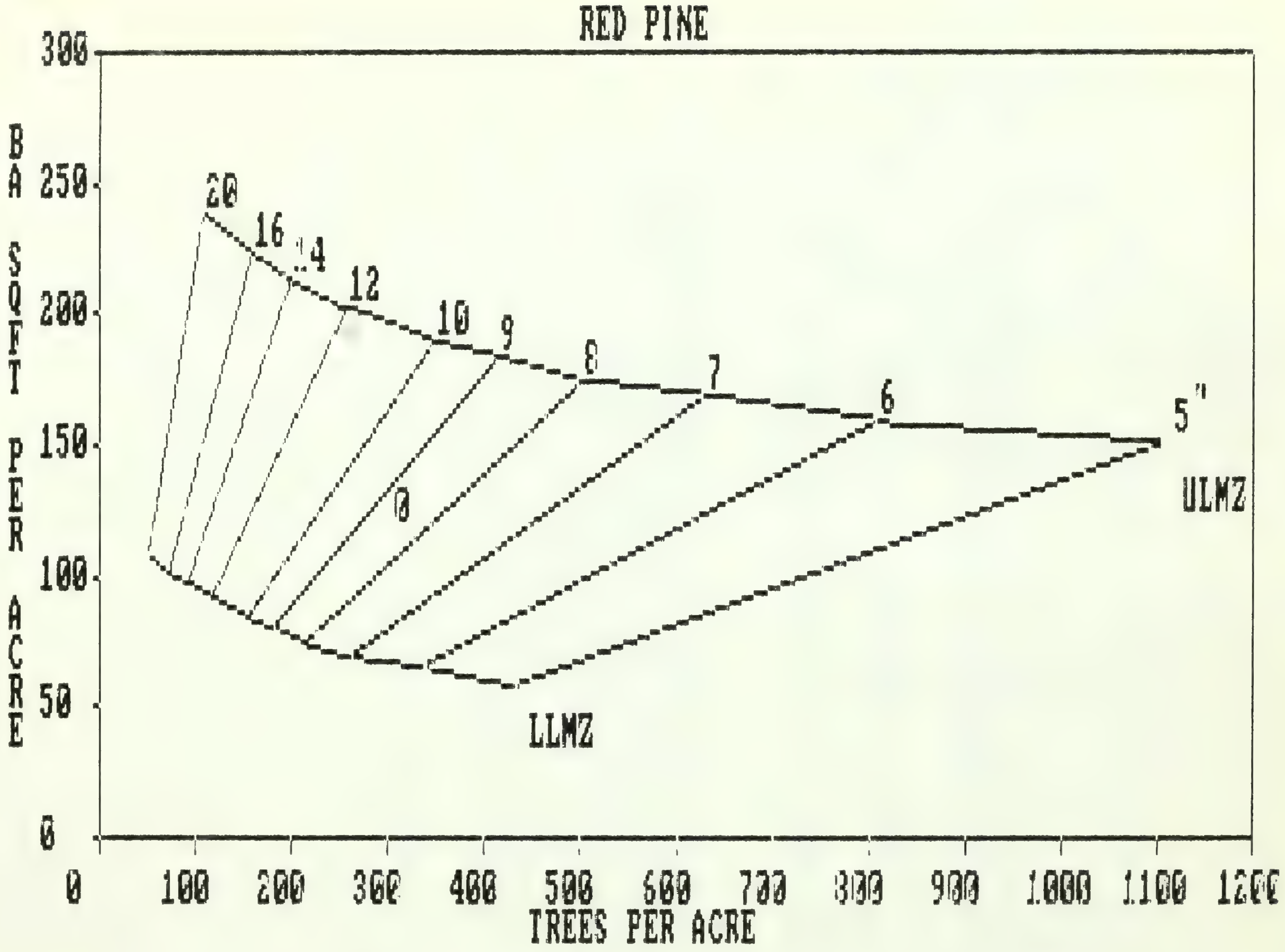
```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::                          S T U M P A G E   R A T E S                     ::
::                                                                          ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

User-defined stumpage rates:

USFS   Sawtimber      Poletimber     Residue
code   $/1000 bdft    $/cord         $/100 cuft
----   -----------    -----------    -----------

 125 $       62.35 $         9.30 $          .00
 129 $       62.35 $         9.30 $          .00
 375 $        9.90 $         2.20 $          .00
 105 $       39.05 $         9.50 $          .00


Default stumpage rates:

       Sawtimber      Poletimber     Residue
       $/1000 bdft    $/cord         $/100 cuft
       -----------    -----------    -----------

     $       29.00 $         6.00 $          .00
```

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                       ::
::            S T A N D   C O N D I T I O N S   F O R   1987             ::
::                                                                       ::
::                          (INITIAL CONDITIONS)                         ::
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Report  for  stand  "COMP  284".   Year=  1987.   INITIAL CONDITIONS. Age= 56,
Cycle= 0,  Site index for RED PINE=  55.0
                                                 Cut          Mortality
               Live        Ba/    Avg   Avg  ------------- -------------  Group
Species gr.   tree/ac     acre    dbh   cai  Tree/ac Ba/ac Tree/ac Ba/ac    si
------------------------------------------------------------------------------
JACK PINE                                                                 56.5
   .0- 4.9          0       .0     .0   .00        0    .0       0    .0
   5.0-10.9        28     12.8    9.0   .00        0    .0       0    .0
  11.0+             7      4.6   11.0   .00        0    .0       0    .0

Group totals       35     17.4    9.4   .00        0    .0       0    .0


RED PINE                                                                  55.0
   .0- 4.9          0       .0     .0   .00        0    .0       0    .0
   5.0-10.9       161     50.1    7.4   .00        0    .0       0    .0
  11.0+            77     56.2   11.5   .00        0    .0       0    .0

Group totals      238    106.3    8.7   .00        0    .0       0    .0


WHITE PINE                                                                53.3
   .0- 4.9          0       .0     .0   .00        0    .0       0    .0
   5.0-10.9         7      2.4    8.0   .00        0    .0       0    .0
  11.0+             0       .0     .0   .00        0    .0       0    .0

Group totals        7      2.4    8.0   .00        0    .0       0    .0


PAP.BIRCH                                                                 54.6
   .0- 4.9          0       .0     .0   .00        0    .0       0    .0
   5.0-10.9        28      6.6    6.5   .00        0    .0       0    .0
  11.0+             0       .0     .0   .00        0    .0       0    .0

Group totals       28      6.6    6.5   .00        0    .0       0    .0


------------------------------------------------------------------------------
All species
   .0- 4.9          0       .0     .0   .00        0    .0       0    .0
   5.0-10.9       224     72.0    7.5   .00        0    .0       0    .0
  11.0+            84     60.9   11.5   .00        0    .0       0    .0
------------------------------------------------------------------------------
Stand totals      308    132.9    8.6   .00        0    .0       0    .0
```

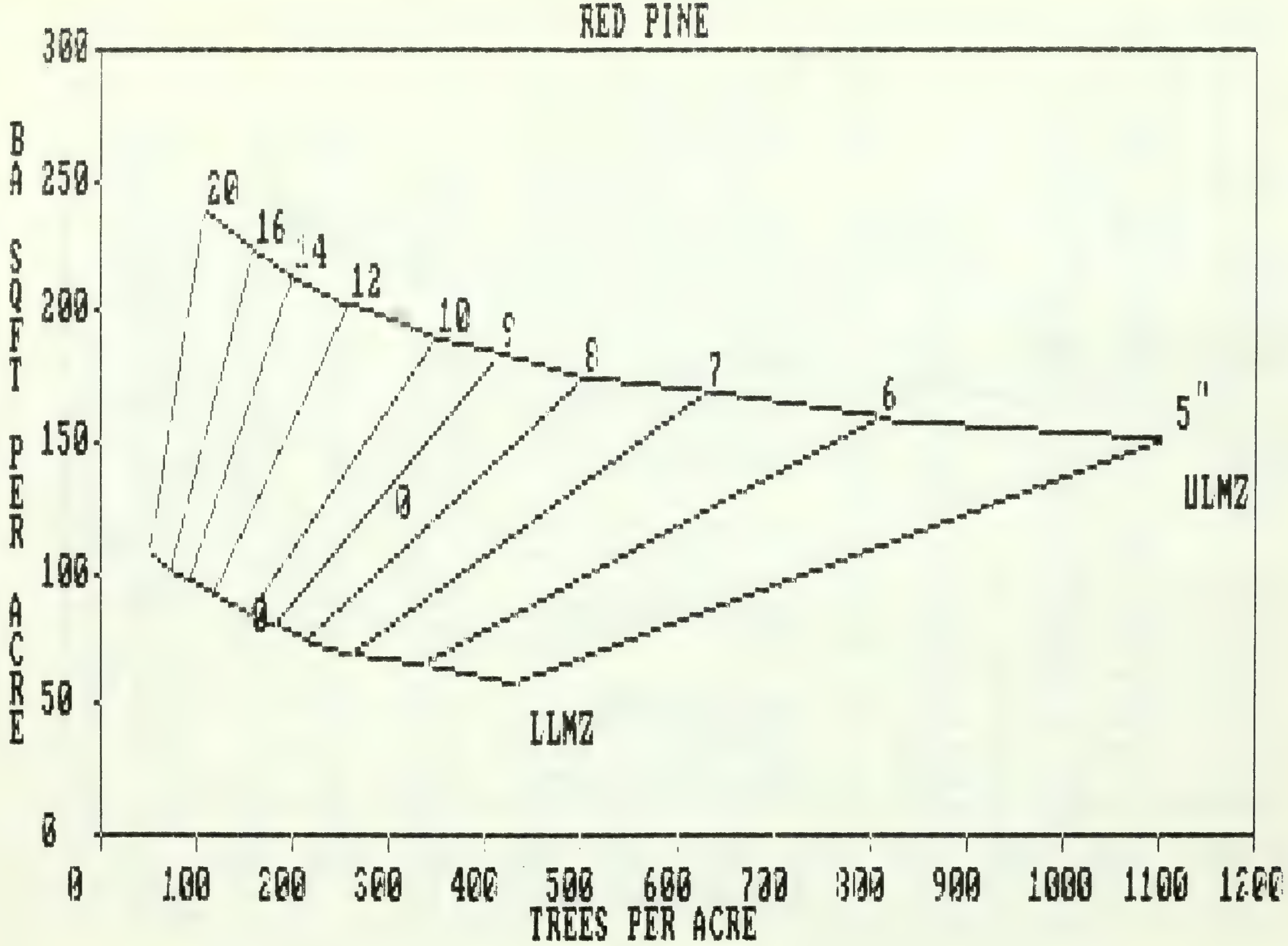
cai = current annual diameter increment.

```
                        S t a n d   V o l u m e
                        -----------------------

                                                      Total
                Sawlog              Pulpwood       Merchantable        Residue
             -------------       -------------    -------------    -------------
Species gr.   cuft      bdft      cuft     cords       cuft          cuft     tons
-------------------------------------------------------------------------------
JACK PINE      224      1094        63        .8        286           151      3.6
RED PINE      1447      7174       501       6.3       1949          1051     21.2
WHITE PINE       0         0        31        .4         31            17       .3
PAP.BIRCH        0         0       125       1.6        125            64      1.6
-------------------------------------------------------------------------------
Stand totals  1671      8268       720       9.1       2391          1283     26.7

Bdft volumes are in SCRIBNER.

mean annual increment =    42.7 cuft/year.


Note:
 - Definition of tree classes:
   20=Acceptable 30=Undesirable, 40=Cull trees.

 - Sawlog volume comes from acceptable trees with a dbh >= 9" (softwood) or with
   a dbh >= 11" (hardwood).  Minimum top sawlog diameters are 7" (softwood) or
   9" (hardwood).

 - Pulpwood volume comes from acceptable and undesirable trees with a dbh >= 5"
   (excluding the sawlog portion of acceptable sawtimber size trees which is
   tallied under sawlog volume).  Minimum top DOB is 4".  One cord equals 79
   cuft.

 - Total merchantable volume is the sum of the sawlog and pulpwood volume.

 - Residue includes volume in tops (<4" DOB to a 1" DOB), limbs, trees less than
   5" DBH, and cull trees.
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                            ::
::                    M A N A G E M E N T   I N   1987                        ::
::                                                                            ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


******************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
******************************************************************************

                                                      Sawlog  [Total  Merch.]
                                             ___ ___
       Trees/ac Batot Basaw Bapole Basap  Dbh Dbh>5    bdft    cuft   cords
 LIVE:      308 132.9  92.3   40.5    .0  8.6   8.6    8268    2391    30.3
 CUT :        0    .0    .0     .0    .0                  0       0      .0
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.


NOTE:  Cycle numbers are used to locate current and previous
stand conditions on the stocking guide.  Cycle 0 represents initial
conditions.  Duplicated numbers indicate before and after cutting.

LLMZ stands for lower level management zone (B-line).
ULMZ stands for upper level management zone (A-line).
```


RED PINE
B A SQFT PER ACRE
300
250
200
150
100
50
0
20
16
14
12
10
9
8
7
6
5"
0
ULMZ
LLMZ
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1200
TREES PER ACRE

```
******************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
******************************************************************************

                                                         Sawlog  [Total  Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh Dbh>5        bdft    cuft   cords
 LIVE:      308 132.9  92.3   40.5    .0  8.6   8.6        8268    2391    30.3
 CUT :        0    .0    .0     .0    .0                      0       0      .0
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

***  Management action:  THIN.

========== Thin in year 1987.  Critical values are:
Thin from below with favored species (most to least favored):
         RED PINE

========== ba, trees, dbh limits for cut are:     90.0 N/A    [none,none]

Tree 13,  PAP.BIRCH   , dbh=  5.0   Cut values: trees/ac=   7.0, ba/ac=   1.0
Tree 10,  JACK PINE   , dbh=  6.0   Cut values: trees/ac=   7.0, ba/ac=   1.4
Tree 14,  PAP.BIRCH   , dbh=  6.0   Cut values: trees/ac=   7.0, ba/ac=   1.4
Tree 15,  PAP.BIRCH   , dbh=  7.0   Cut values: trees/ac=   7.0, ba/ac=   1.9
Tree 16,  PAP.BIRCH   , dbh=  8.0   Cut values: trees/ac=   7.0, ba/ac=   2.4
Tree 17,  WHITE PINE  , dbh=  8.0   Cut values: trees/ac=   7.0, ba/ac=   2.4
Tree 11,  JACK PINE   , dbh= 10.0   Cut values: trees/ac=  21.0, ba/ac=  11.5
Tree 12,  JACK PINE   , dbh= 11.0   Cut values: trees/ac=   7.0, ba/ac=   4.6
Tree  1,  RED PINE    , dbh=  5.0   Cut values: trees/ac=  28.0, ba/ac=   3.8
Tree  2,  RED PINE    , dbh=  6.0   Cut values: trees/ac=  21.0, ba/ac=   4.1
Tree  3,  RED PINE    , dbh=  7.0   Cut values: trees/ac=  28.0, ba/ac=   7.5
Tree 18,  RED PINE    , dbh=  8.0   Cut values: trees/ac=   2.6, ba/ac=    .9
Thinning is complete for year 1987

******************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
******************************************************************************

                                                         Sawlog  [Total  Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh Dbh>5        bdft    cuft   cords
 LIVE:      158  90.0  76.2   13.8    .0 10.1  10.1        7174    1731    21.9
 CUT :      150  42.9  16.1   26.8    .0                   1094     659     8.3
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

NOTE:  Cycle numbers are used to locate current and previous
stand conditions on the stocking guide.  Cycle 0 represents initial
conditions.  Duplicated numbers indicate before and after cutting.

LLMZ stands for lower level management zone (B-line).
ULMZ stands for upper level management zone (A-line).
```


RED PINE
B A SQFT PER ACRE
0
50
100
150
200
250
300
TREES PER ACRE
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
20
16
14
12
10
9
8
7
6
5"
0
0
ULMZ
LLMZ

```
******************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
******************************************************************************

                                                       Sawlog  [Total Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh Dbh>5     bdft    cuft   cords
 LIVE:      158  90.0  76.2   13.8    .0 10.1  10.1     7174    1731    21.9
 CUT :      150  42.9  16.1   26.8    .0                1094     659     8.3
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.


***  Management action:  VALUE AFTER MANAGEMENT.


Income from sale of cut trees in 1987 is $   82.95 per acre.

Sawlogs  =      1094 bdft,  $   42.71
Pulpwood =       5.5 cords, $   40.24
Residue  =     347.3 cuft,  $     .00

Value of residual stand (all live trees) is $   480.73 per acre.

Sawlogs  =      7174 bdft,  $  447.30
Pulpwood =       3.6 cords, $   33.43
Residue  =     935.7 cuft,  $     .00


Management complete for year 1987
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::          S T A N D   C O N D I T I O N S   F O R   1987                  ::
::                                                                          ::
::                          (AFTER MANAGEMENT)                              ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Report for stand "COMP 284".   Year= 1987.  AFTER MANAGEMENT.
Age= 56,  Cycle= 0,  Site index for RED PINE=  55.0
                                                    Cut        Mortality
                 Live       Ba/    Avg    Avg   ------------- -------------   Group
Species gr.    tree/ac     acre    dbh    cai   Tree/ac Ba/ac Tree/ac Ba/ac     si
------------------------------------------------------------------------------------
JACK PINE                                                                     56.5
   .0- 4.9          0       .0     .0    .00        0    .0        0    .0
  5.0-10.9          0       .0     .0    .00       28  12.8        0    .0
  11.0+             0       .0     .0    .00        7   4.6        0    .0

Group totals        0       .0     .0    .00       35  17.4        0    .0


RED PINE                                                                      55.0
   .0- 4.9          0       .0     .0    .00        0    .0        0    .0
  5.0-10.9         81     33.8    8.7    .00       80  16.3        0    .0
  11.0+            77     56.2   11.5    .00        0    .0        0    .0

Group totals      158     90.0   10.1    .00       80  16.3        0    .0


WHITE PINE                                                                    53.3
   .0- 4.9          0       .0     .0    .00        0    .0        0    .0
  5.0-10.9          0       .0     .0    .00        7   2.4        0    .0
  11.0+             0       .0     .0    .00        0    .0        0    .0

Group totals        0       .0     .0    .00        7   2.4        0    .0


PAP.BIRCH                                                                     54.6
   .0- 4.9          0       .0     .0    .00        0    .0        0    .0
  5.0-10.9          0       .0     .0    .00       28   6.6        0    .0
  11.0+             0       .0     .0    .00        0    .0        0    .0

Group totals        0       .0     .0    .00       28   6.6        0    .0


------------------------------------------------------------------------------------
All species
   .0- 4.9          0       .0     .0    .00        0    .0        0    .0
  5.0-10.9         81     33.8    8.7    .00      143  38.2        0    .0
  11.0+            77     56.2   11.5    .00        7   4.6        0    .0
------------------------------------------------------------------------------------
Stand totals      158     90.0   10.1    .00      150  42.9        0    .0
cai = current annual diameter increment.
```

```
                          S t a n d   V o l u m e
                          -----------------------

                                                          Total
                   Sawlog              Pulpwood        Merchantable         Residue
               -------------        -------------     -------------     -------------
Species gr.    cuft      bdft        cuft    cords         cuft          cuft      tons
-------------------------------------------------------------------------------------
JACK PINE         0         0           0       .0            0             0        .0
RED PINE       1447      7174         284      3.6         1731           936      18.8
WHITE PINE        0         0           0       .0            0             0        .0
PAP.BIRCH         0         0           0       .0            0             0        .0
-------------------------------------------------------------------------------------
Stand totals   1447      7174         284      3.6         1731           936      18.8

Bdft volumes are in SCRIBNER.
mean annual increment = 42.7 cuft/year.
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::                        Begin cycle  1 for 1987                           ::
::                                                                          ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


Trees will be projected in  20 intervals for a total of  20 years.
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                      ::
::           S T A N D   C O N D I T I O N S   F O R   2007            ::
::                                                                      ::
::                     (AFTER PROJECTION CYCLE)                         ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Report for stand "COMP 284".   Year= 2007.  AFTER PROJECTION CYCLE.
Age= 76,  Cycle= 1,  Site index for RED PINE=  55.0
                                                     Cut          Mortality
                 Live       Ba/    Avg    Avg   ------------- -------------   Group
Species gr.    tree/ac     acre    dbh    cai   Tree/ac Ba/ac Tree/ac Ba/ac     si
-------------------------------------------------------------------------------
RED PINE                                                                      55.0
   .0- 4.9           0       .0     .0    .00         0    .0       0    .0
  5.0-10.9          39     24.3   10.7    .11         0    .0       0    .2
 11.0+             118    117.7   13.5    .11         0    .0       1    .5

Group totals       157    142.1   12.8    .11         0    .0       1    .7


-------------------------------------------------------------------------------
All species
   .0- 4.9           0       .0     .0    .00         0    .0       0    .0
  5.0-10.9          39     24.3   10.7    .11         0    .0       0    .2
 11.0+             118    117.7   13.5    .11         0    .0       1    .5
-------------------------------------------------------------------------------
Stand totals       157    142.1   12.8    .11         0    .0       1    .7

cai = current annual diameter increment.
Note: Mortality values are for  1987 to 2007
```

```
                       S t a n d   V o l u m e
                       ------------------------

                                                   Total
                 Sawlog             Pulpwood     Merchantable       Residue
              -------------      -------------   -------------   -------------
Species gr.   cuft      bdft      cuft    cords       cuft        cuft      tons
------------------------------------------------------------------------------
RED PINE      2903     15534       157      2.0       3061        1676      33.3
------------------------------------------------------------------------------
Stand totals  2903     15534       157      2.0       3061        1676      33.3

Bdft volumes are in SCRIBNER.

mean annual increment = 48.9 cuft/year.
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::                   M A N A G E M E N T   I N   2007                       ::
::                                                                          ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::



*****************************************************************************
Current stand statistics: 2007, cycle  1 for stand "COMP 284".
*****************************************************************************

                                                        Sawlog  [Total Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh  Dbh>5     bdft     cuft   cords
 LIVE:      157 142.1 142.1     .0    .0 12.8   12.8    15534     3061    38.7
 CUT :        0    .0    .0     .0    .0                    0        0      .0
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.



***  Management action:  CLEARCUT.


========== Clearcut in  2007  Cut values are:
========== 157.46 trees/acre and   142.06 basal area cut.
```

```
******************************************************************************
Current stand statistics: 2007, cycle  1 for stand "COMP 284".
******************************************************************************

                                                      Sawlog  [Total Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh Dbh>5    bdft    cuft   cords
 LIVE:        0    .0    .0     .0    .0   .0    .0       0       0      .0
 CUT :      157 142.1 142.1     .0    .0              15534    3061    38.7
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.


***  Management action:  VALUE AFTER MANAGEMENT.


Income from sale of cut trees in 2007 is $  987.07 per acre.

Sawlogs  =     15534 bdft,  $  968.57
Pulpwood =       2.0 cords, $   18.50
Residue  =    1675.8 cuft,  $     .00

Value of residual stand (all live trees) is $     .00 per acre.

Sawlogs  =         0 bdft,  $     .00
Pulpwood =        .0 cords, $     .00
Residue  =        .0 cuft,  $     .00


Management complete for year 2007
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                        ::
::          S T A N D   C O N D I T I O N S   F O R   2007                ::
::                                                                        ::
::                          (AFTER MANAGEMENT)                            ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Report for stand "COMP 284".   Year= 2007.  AFTER MANAGEMENT.
Age= 76,  Cycle= 1,  Site index for RED PINE=  55.0
                                                 Cut          Mortality
              Live        Ba/    Avg   Avg   ------------- -------------   Group
Species gr.   tree/ac     acre   dbh   cai   Tree/ac Ba/ac Tree/ac Ba/ac     si
------------------------------------------------------------------------------
RED PINE                                                                  55.0
   .0- 4.9         0        .0     .0   .00       0    .0       0    .0
  5.0-10.9         0        .0     .0   .00      39  24.3       0    .2
 11.0+             0        .0     .0   .00     118 117.7       1    .5

Group totals       0        .0     .0   .00     157 142.1       1    .7


------------------------------------------------------------------------------
All species
   .0- 4.9         0        .0     .0   .00       0    .0       0    .0
  5.0-10.9         0        .0     .0   .00      39  24.3       0    .2
 11.0+             0        .0     .0   .00     118 117.7       1    .5
------------------------------------------------------------------------------
Stand totals       0        .0     .0   .00     157 142.1       1    .7

cai = current annual diameter increment.
Note: Mortality values are for 1987 to 2007
      Cut values are for year 2007 only.


                          S t a n d   V o l u m e
                          -----------------------

                                                 Total
                Sawlog            Pulpwood    Merchantable      Residue
              -------------   -------------  -------------   -------------
Species gr.   cuft     bdft      cuft    cords     cuft       cuft      tons
------------------------------------------------------------------------------
RED PINE         0        0         0      .0        0          0        .0
------------------------------------------------------------------------------
Stand totals     0        0         0      .0        0          0        .0


Bdft volumes are in SCRIBNER.

mean annual increment =    48.9 cuft/year
```

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                           ::
::                       E C O N O M I C S   F O R   2007                    ::
::                                                                           ::
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::



      ANALYSIS FOR STAND: COMP 284
      STAND AGE IN 2007 IS  76 YEARS


                        ECONOMIC ANALYSIS INPUTS

      NOMINAL DISCOUNT RATE                            7.00%
      GENERAL INFLATION RATE                           4.00%
      STUMPAGE PRICE INFLATION RATE                    1.20%
      BASE YEAR FOR THE ANALYSIS                       1987
      END YEAR FOR THE ANALYSIS                        2007


DIARY OF COST AND REVENUE ACTIVITIES:

          (ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY      NAME          YEAR(S)        COST      REVENUE    INFLATION RATE
_____   ___________   __________   _________   _________   _____________
  1     Buy Land         1987        300.00         .00           .00
  2     Property Tax   1987-2007        .90         .00           .00
  3     Sale Prep.       1987         65.00         .00           .00
                         2007         65.00         .00           .00
  4     Sale Admin.      1987         22.00         .00           .00
                         2007         22.00         .00           .00
  5     Sell Land        2007           .00      300.00           .00
  6     SALE INCOME      1987           .00       82.95          1.20
  7     SALE INCOME      2007           .00      987.07          1.20
---------------------------------------------------------------------------
```

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	YEAR 1987	1988	1989	1990	1991
Buy Land	300.00	.00	.00	.00	.00
Property Tax	.90	.94	.97	1.01	1.05
Sale Prep.	65.00	.00	.00	.00	.00
Sale Admin.	22.00	.00	.00	.00	.00
TOT ANN COST	387.90	.94	.97	1.01	1.05
CUM TOT COST	387.90	388.84	389.81	390.82	391.87
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	82.95	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	82.95	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-304.95	-.94	-.97	-1.01	-1.05
CUM NET REV	-304.95	-305.88	-306.86	-307.87	-308.92

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	YEAR 1992	1993	1994	1995	1996
Buy Land	.00	.00	.00	.00	.00
Property Tax	1.09	1.14	1.18	1.23	1.28
Sale Prep.	.00	.00	.00	.00	.00
Sale Admin.	.00	.00	.00	.00	.00
TOT ANN COST	1.09	1.14	1.18	1.23	1.28
CUM TOT COST	392.97	394.11	395.29	396.52	397.81
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	.00	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-1.09	-1.14	-1.18	-1.23	-1.28
CUM NET REV	-310.02	-311.16	-312.34	-313.57	-314.85

```
                          ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

                                                    YEAR
       ITEM             1997        1998        1999        2000        2001
=============================================================================
    Buy Land             .00         .00         .00         .00         .00
    Property Tax        1.33        1.39        1.44        1.50        1.56
    Sale Prep.           .00         .00         .00         .00         .00
    Sale Admin.          .00         .00         .00         .00         .00
-----------------------------------------------------------------------------
    TOT ANN COST        1.33        1.39        1.44        1.50        1.56
    CUM TOT COST      399.14      400.52      401.96      403.46      405.02
=============================================================================
    Sell Land            .00         .00         .00         .00         .00
    SALE INCOME          .00         .00         .00         .00         .00
    SALE INCOME          .00         .00         .00         .00         .00
-----------------------------------------------------------------------------
    TOT ANN RECP         .00         .00         .00         .00         .00
    CUM TOT RECP       82.95       82.95       82.95       82.95       82.95
=============================================================================
    ANN NET REV        -1.33       -1.39       -1.44       -1.50       -1.56
    CUM NET REV      -316.19     -317.57     -319.01     -320.51     -322.07
=============================================================================
```

```
                          ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

                                                    YEAR
       ITEM             2002        2003        2004        2005        2006
=============================================================================
    Buy Land             .00         .00         .00         .00         .00
    Property Tax        1.62        1.69        1.75        1.82        1.90
    Sale Prep.           .00         .00         .00         .00         .00
    Sale Admin.          .00         .00         .00         .00         .00
-----------------------------------------------------------------------------
    TOT ANN COST        1.62        1.69        1.75        1.82        1.90
    CUM TOT COST      406.64      408.33      410.08      411.90      413.80
=============================================================================
    Sell Land            .00         .00         .00         .00         .00
    SALE INCOME          .00         .00         .00         .00         .00
    SALE INCOME          .00         .00         .00         .00         .00
-----------------------------------------------------------------------------
    TOT ANN RECP         .00         .00         .00         .00         .00
    CUM TOT RECP       82.95       82.95       82.95       82.95       82.95
=============================================================================
    ANN NET REV        -1.62       -1.69       -1.75       -1.82       -1.90
    CUM NET REV      -323.69     -325.38     -327.13     -328.95     -330.85
=============================================================================
                           ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

                                                YEAR
       ITEM         2007
=============================================================================
    Buy Land           .00
    Property Tax      1.97
    Sale Prep.      142.42
    Sale Admin.      48.20
-----------------------------------------------------------------------------
    TOT ANN COST    192.60
    CUM TOT COST    606.40
=============================================================================
    Sell Land       657.34
    SALE INCOME        .00
    SALE INCOME    2745.51
-----------------------------------------------------------------------------
    TOT ANN RECP   3402.85
    CUM TOT RECP   3485.80
=============================================================================
    ANN NET REV    3210.25
    CUM NET REV    2879.40
=============================================================================
PROFILE OF NET PRESENT VALUE (NPV) FOR THE INVESTMENT AT VARIOUS DISCOUNT RATES
                      (INVESTMENT LENGTH =  21 YEARS)

              (NPV VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

      REAL RATE             NOMINAL RATE                   NPV
--------------------------------------------------------------------------------
          .00%                 4.00%                 $    1143.06
         2.00%                 6.08%                 $     666.91
         4.00%                 8.16%                 $     351.89
         6.00%                10.24%                 $     141.83
         8.00%                12.32%                 $        .75
        10.00%                14.40%                 $     -94.70
        12.00%                16.48%                 $    -159.69
        14.00%                18.56%                 $    -204.24
        16.00%                20.64%                 $    -234.95
        18.00%                22.72%                 $    -256.25
        20.00%                24.80%                 $    -271.09
        22.00%                26.88%                 $    -281.49
        24.00%                28.96%                 $    -288.80
        26.00%                31.04%                 $    -293.96
        28.00%                33.12%                 $    -297.62
        30.00%                35.20%                 $    -300.22
        32.00%                37.28%                 $    -302.07
        34.00%                39.36%                 $    -303.38
        36.00%                41.44%                 $    -304.32
        38.00%                43.52%                 $    -304.98
        40.00%                45.60%                 $    -305.44
        42.00%                47.68%                 $    -305.77
        44.00%                49.76%                 $    -305.99
        46.00%                51.84%                 $    -306.15
        48.00%                53.92%                 $    -306.25
        50.00%                56.00%                 $    -306.31
------------------------------------------------------------------------------
```

```
                    INVESTMENT PERFORMANCE ANALYSIS

 NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                    (INVESTMENT LENGTH =  21 YEARS)

      (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

--------------------------------------------------------------------------
     NET PRESENT VALUE (NPV)                              $     511.62

     EQUIVALENT ANNUAL INCOME (EAI)                       $      34.02

     SOIL EXPECTATION VALUE (SEV)                         $    1179.49

     BENEFIT/COST RATIO                                           2.14

     YEARS TO PAY BACK AT DISCOUNT                            20 YEARS

     REAL INTERNAL RATE OF RETURN                                8.01%

     NOMINAL INTERNAL RATE OF RETURN                            12.33%
--------------------------------------------------------------------------

  Soil Expectation Value (SEV) is the capitalized value of an infinitely long
  series of cash flows associated with a timber management alternative that
  starts with BARE LAND.  While a SEV was determined from the inputted cash
  flows, the calculated value is not appropriate for interpretation unless
  the base year for the analysis was set to the year of planting, all timber
  management cash flows were incorporated for the entire rotation, and all
  cash flows were in base year dollars.  Land purchase costs and land sale
  returns must be removed from the cash flow stream before SEV is computed.
```

```
                         SENSITIVITY ANALYSIS


      (SENSITIVITY OF PERFORMANCE TO A 10% CHANGE IN INPUT VALUES)
  NOMINAL DISCOUNT RATE =  7.00%      GENERAL INFLATION RATE =  4.00%
                      (INVESTMENT LENGTH =  21 YEARS)

        (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

 ITEM CHANGED         NPV CHANGE         EAI CHANGE         SEV CHANGE
----------------------------------------------------------------------------
 Buy Land        $         30.00    $         2.00    $         69.16
 Property Tax    $          1.44    $          .10    $          3.33
 Sale Prep.      $         10.18    $          .68    $         23.47
 Sale Admin.     $          3.45    $          .23    $          7.94
============================================================================
 Sell Land       $         16.99    $         1.13    $         39.16
 SALE INCOME     $          8.30    $          .55    $         19.12
 SALE INCOME     $         70.95    $         4.72    $        163.57
============================================================================

 Soil Expectation Value (SEV) is the capitalized value of an infinitely long
 series of cash flows associated with a timber management alternative that
 starts with BARE LAND.  While a SEV sensitivity analysis was performed for
 investment cash flows, the calculated values are not appropriate for
 interpretation unless the base year for the analysis was set to the year of
 planting, all timber management cash flows were incorporated for the entire
 rotation, and all cash flows were in base year dollars.  Land purchase
 costs and land sale returns must be removed from the cash flow stream
 before SEV sensitivity analysis is computed.
```

```
                              RISK ANALYSIS


     (INPUT VALUE CHANGES WHICH WILL MAKE NPV EXACTLY EQUAL TO $0.00)
  NOMINAL DISCOUNT RATE =  7.00%       GENERAL INFLATION RATE =  4.00%
                      (INVESTMENT LENGTH =  21 YEARS)

          (ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

    ITEM CHANGED                 PERCENT CHANGE             DOLLAR CHANGE
--------------------------------------------------------------------------
    Buy Land                        100.00%               $     -300.00
    Property Tax                    100.00%               $      -14.43
    Sale Prep.                      100.00%               $     -101.81
    Sale Admin.                     100.00%               $      -34.46
==========================================================================
    Sell Land                      -100.00%               $     -169.87
    SALE INCOME                    -100.00%               $      -82.95
    SALE INCOME                     -72.11%               $     -511.62
==========================================================================


OTE:  WHEN PERCENT CHANGE EQUALS 100% AND DOLLAR CHANGE IS SMALLER THAN
      $    511.62, THE INPUT VARIABLE WILL NOT ALTER THE OVERALL INVESTMENT
      SELECTION, GIVEN THE CURRENT DECISION CRITERIA.


===========================================================================
rojection is complete for this stand.
```

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                         ::
::               Summary of Management and Growth Projection               ::
::                                                                         ::
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Stand Description:
------------------
Stand Name: COMP 284
Initial Year of Projection: 1987
Initial Age:  56
Site Index Species: RED PINE          Site Index: 55.0

Management Applied:
-------------------

 Thin, from below to  90 square feet of basal area in 1987
 Clearcut in 2007

                                                       VOLUME
                                        ------------------------------------
                                           Sawlog      Pulpwood    Residual
            Mgmt   Trees/ac   Ba/  Ave  ------------  ----------  ----------
Year  age  Status Live Died   ac   dbh  Cuft    Bdft  Cuft  Cord  Cuft  Tons
-----------------------------------------------------------------------------
1987   56  BEFORE 308     0  133   8.6  1671    8268   720     9  1283    27
1987   56  CUT    150     0   43    .0   224    1094   436     6   347     8
1987   56  AFTER  158     0   90  10.1  1447    7174   284     4   936    19


2007   76  BEFORE 157     1  142  12.8  2903   15534   157     2  1676    33
2007   76  CUT    157     0  142    .0  2903   15534   157     2  1676    33
2007   76  AFTER    0     1    0    .0     0       0     0     0     0     0
```

APPENDIX H

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Descriptions of STEMS and TWIGS and Their Components

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This is a complete reference to TWIGS, a forest growth-and-yield program with management and economic components developed for Lake and Central States tree species. The guide describes how TWIGS models growth and yield and how the model can be applied to obtain the best results. Step-by-step operating instructions are provided for TWIGS and its companion program, TREEGEN, which generates tree lists in readable format for TWIGS. The appendices include equations, coefficients, validation tables, and an example printout of a projection run.

KEY WORDS: Growth and yield (simulation), forest stand management (simulation), economics, computer programs (forestry), silviculture, STEMS.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL
FOREST
EXPERIMENT STATION

United States Department of Agriculture

Forest Service

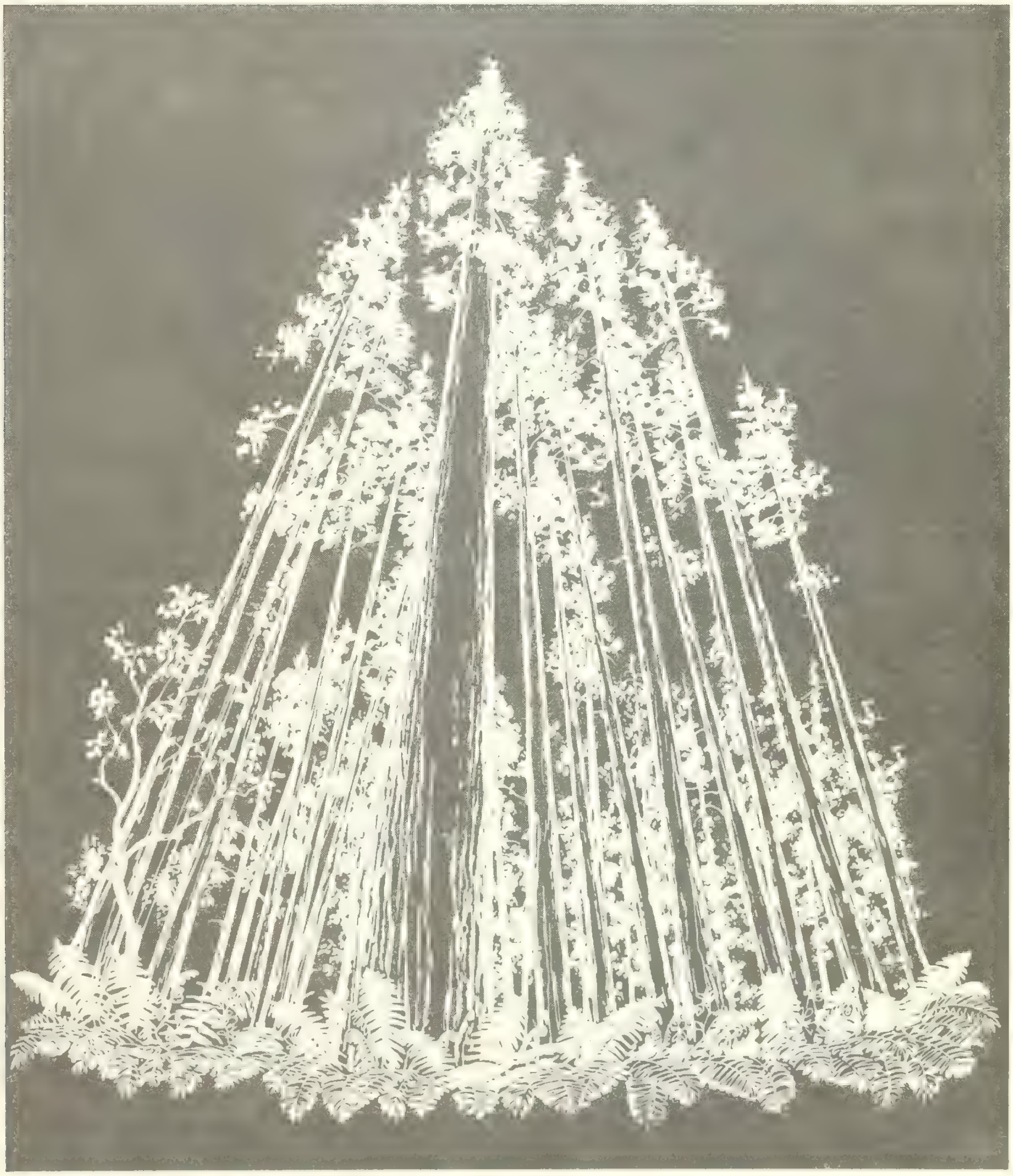
North Central Forest Experiment Station

General Technical Report **NC-126**

The Status of Forest Management Research in the United States

Donald G. Hodges, Pamela J. Jakes, and Frederick W. Cubbage

PUBLIC DOCUMENTS



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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
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1988

The Status of Forest Management Research in the United States

Donald G. Hodges, Pamela J. Jakes, and Frederick W. Cubbage

Introduction

Evaluating the benefits and costs of forestry research has become an important task for forest economists and policymakers. Despite extensive literature on agricultural research evaluation (see, for example, Norton and Davis 1981, Ruttan 1982, and Bengston 1985a), widespread interest in the impacts of forestry research only began in this decade.

Examination of public forestry research was encouraged by the passage of RPA, the Forest and Rangeland Renewable Resources Planning Act of 1974 (PL 93-378). This legislation requires the USDA Forest Service to periodically evaluate the status of renewable natural resources and to propose programs, including research, for properly managing these resources.

The climate and concerns that led to the passage of the RPA have also resulted in more public participation in science and technology. Researchers and research managers are being held accountable for the impacts of their research. In agriculture, research managers have been widely criticized for not giving enough attention to the social consequences of their research (Sun 1984, Martin and Olmstead 1985). Forestry research managers also need to measure and predict the impacts of research to address public questions and concerns.

Interest in evaluating the impacts of forestry research has also been spurred by declining research budgets. Growth in the public research and development budget for natural resources in the U.S. has lagged far behind that for agricultural research and development (fig. 1). Agricultural research evaluations carried out over the past two decades have consistently shown high rates of return to agricultural research (Evenson *et al.* 1979). This has resulted in the widespread perception that investment in agricultural research benefits society, and may help to explain increasing research benefits (Fedkiw 1985). Although

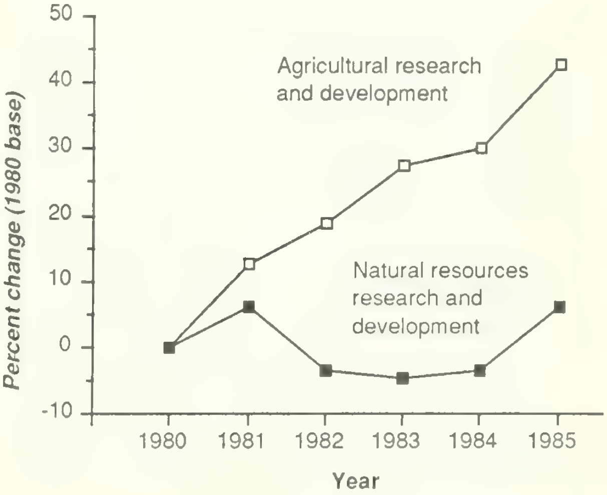

Figure 1.--*Percent change in federal research and development budgets for natural resources and agriculture, 1980-1985 (National Science Foundation 1986).*

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research in forestry and other natural resources may produce similar high payoffs, empirical evidence supporting this hypothesis has been lacking until quite recently.

In response to the growing interest in evaluating the impacts of forestry research, the Forest Service has been conducting research at the North Central Forest Experiment Station on methods for evaluating forestry research. In addition to this effort, the Forest Service supports research on research evaluation methods at universities across the country.

Evaluating Forestry Research—Research Needs

Recent investments in forestry research evaluation have resulted in a growing body of literature evaluating the impacts of specific forestry research innovations (table 1). Despite these accomplishments, gaps remain in our knowledge and skills. First, agriculture and forestry research evaluations have almost exclusively analyzed completed research projects that have already produced innovations that are being, or have been, adopted. Evaluations of past efforts are of little value to research managers who must decide on current or future research programs. If evaluations are to be useful in research planning, management, and policymaking, *ex ante* (before research implementation) evaluation methods and case studies are needed.

Second, most of the forestry research evaluations that have been conducted are narrowly focused case studies that may not be representative of a broad research area or discipline. We need to conduct more aggregate-level evaluations that examine the relation between research in a broad area and the growth or productivity in an entire industry or sector of the economy.

Third, although research innovations produce a variety of impacts—including impacts on employment, trade, market structure, and the environment—most of the forestry research evaluations conducted thus far have measured just the economic efficiency of the research investment. Economic efficiency is seldom the only important criterion in evaluating research programs—other impacts should also be considered.

Finally, evaluations have focused primarily on forest products and utilization research. This focus on products is natural given that many existing forestry research evaluations use methods developed for agricultural research evaluation—evaluations that analyze, almost exclusively, agricultural commodities. Forestry's concentration on products can also be attributed to the availability of vital forest products market data, which are scarce or non-existent in other areas of forestry. However, by focusing on forest products and utilization research, we have ignored several major research disciplines, including forest management research.

Table 1.—*Evaluating the impacts of forestry research—results from case studies*

Study	Measure of economic efficiency
Percent rate of return	
Forest pest management research (Araji 1981)	60-87
Timber utilization research (Haygreen *et al.* 1983)	14-36
Structural particleboard research (Bengston 1984)	18-22
Forest nutrition research (Bare 1985)	9-12
Lumber and wood products research (Bengston 1985b)	34-40
Southern softwood forestry research (Newman 1986)	Negative to > 10
Containerized forest tree seedling research (Westgate 1986)	37-111
Softwood plywood research (Seldon 1987)	220-410
Other measures	
Tree improvement research in Michigan (Net Present Value) (Levenson 1984)	$262 million
Growth and yield models (Benefit:Cost Ratio) (Chang 1985)	16:1
Wood preservation (Benefit:Cost Ratio) (Brunner and Strauss 1987)	15-66:1

Evaluating Forest Management Research

Forest management research is research directed at increasing the biological or economic productivity of forest land. Although this area receives a large percentage of total forestry research funding, it has received little attention from individuals interested in research evaluation. This is due to several factors (fig. 2).

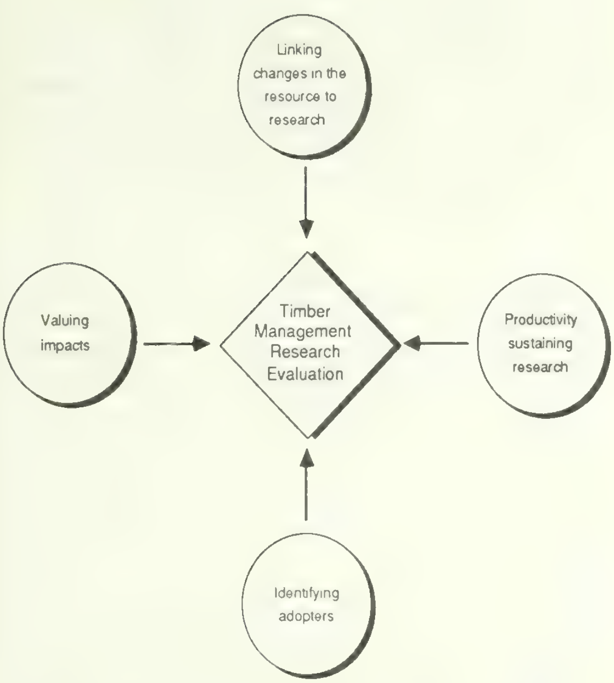

Linking changes in the resource to research
Valuing impacts
Timber Management Research Evaluation
Productivity sustaining research
Identifying adopters

Figure 2.--*Factors complicating the evaluation of forest management research.*

First, it is often difficult to link changes in forest resource conditions directly to forest management research. Research evaluation requires a clear demonstration that changes in the resource are in response to the adoption of new management techniques or other technologies resulting from a research effort, rather than variations in climate, species composition, site, or other factors.

A related challenge in evaluating forest management research is the fact that a large share of this research may be classified as productivity sustaining research. Productivity sustaining research is research necessary to maintain current productivity levels. So, we must be able to identify not only the increases in productivity due to research efforts, but also the losses avoided because research has provided methods of maintaining soil productivity, managing insect populations, and other innovations.

Even if the impacts of a research innovation can be identified, there can be problems valuing these impacts. Unlike many areas of forest products research, innovations in the biological aspects of forest management lack direct consumer market prices—their values are reflected in timber stumpage prices, which vary widely among individual sales, species, regions, and by other factors.

Finally, an important step in evaluating research impacts is identifying potential adopters of a new technology and factors affecting their rate of adoption. Forest products research deals with an easily identifiable group of adopters—profit-maximizing companies, many of whom maintain direct, daily contact with researchers in their areas of interest. In contrast, forest management innovations may be adopted by public, industrial, or private nonindustrial forest land owners. Each of these ownership classes possesses different ownership and management objectives. Objectives differ widely within ownership classes as well.

These difficulties—of identifying impacts, accounting for productivity sustaining research, valuing impacts, and forecasting adoption—have discouraged many analysts from estimating the impacts of forest management research. However, despite these problems, some researchers have tested the use of existing methods on evaluating forest management research. Most case studies have found positive returns, although lower than those reported in evaluations of forest products and utilization innovations.

Levenson (1984) calculated the net present value of tree improvement research in Michigan to be $262 million. He further found that a typical pulp and paper company could derive a benefit of $1 million from this research. Benefits received by the State of Michigan's public forestry programs were estimated to exceed $5.5 million. Bare (1985) estimated internal rates of return of 9 to 12 percent for the Regional Forest Nutrition Research Program at the University of Washington. The range of values reflects varying assumptions on the percentage of total fertilized acres in the region attributable to nutrition research. An evaluation of biometrics research estimated a benefit-cost ratio of 16.3 for a recently developed growth and yield model for oaks in New England (Chang 1985). Similarly, investments in containerized forest tree seedling research yielded annual internal rates of return ranging from 37 to 111 percent, depending on the price differential between bare-root and containerized seedlings (Westgate 1986). In contrast Newman (1986) found average annual benefits of $1.3 to 5.4 million from aggregate technical change in southern softwood forestry compared to annual research expenditures of more than $6.5 million.

Objectives

The case studies cited above have helped identify the difficulties of using traditional methods to evaluate forest management research. New methods are needed to overcome these difficulties, and provide policy and decision makers with tools for evaluating forest management research.

As a first step in developing a new framework for evaluating forest management research, we have estimated the extent and distribution of the total U.S. forest management research effort. The analysis involved (1) defining forest management research; (2) describing and measuring inputs, outputs, and research in progress in the Forest Service, forest industries, and universities (to the extent possible); and (3) describing the distribution of forest management research benefits among geographic regions and ownership classes.

Methods

Defining Forest Management Research

The Forest Service conducts research identified as "Timber Management Research" (TMR). Forest Service TMR covers research related to silviculture, mensuration, genetics, and timber related resources. The Society of American Foresters (1983) defines forest management as "... that branch of forestry concerned... with the essentially scientific and technical aspects [of] silviculture, protection, and forest regulation". This definition encompasses forest regulation and protection research, areas missing from TMR. By combining these two definitions, we arrived at a third definition (used in this study) that defines forest management research as research related to silviculture (including prescribed burning), mensuration, genetics, and the economics of forest management. Protection research was not included in the analysis because extensive literature already addresses this topic (see, for example, Cleland *et al.* 1982, Rose 1983). Also, forest protection and atmospheric sciences (fire) research represents major costs and benefits that would cloud an evaluation of traditional forest management research. We included prescribed burning because it is a tool for managing the resource rather than protecting it.

Acquiring Data

Three principal sectors in the United States perform forest management research—the Forest Service, forest industries, and universities. Each sector's research efforts have unique characteristics, and the information available for each program differs greatly. The Forest Service has the most detailed records of research inputs, process, and outputs. Forestry schools keep modest records on expenditures. Much of the industry research information is proprietary.

USDA Forest Service

The Forest Service's research effort is directed from eight regional forest experiment stations across the country and the Forest Products Laboratory in Madison, Wisconsin. Each station has research work units, which conduct studies that help to solve problems identified in each research work unit's description.

We determined the inputs and outputs of Forest Service forest management research from the annual research attainment reports of each forest experiment station for fiscal years 1980 through 1985. Attainment reports summarize each work unit's accomplishments, including the number of active and inactive studies, personnel employed, funds expended, and publications and patents produced. We recorded this information for each work unit conducting forest management research.

Research is often described as being applied or practical as opposed to basic or theoretical. Although these terms have become value-laden, they are useful in describing the intended audience or immediate user of the research. Based on the information contained in the attainment reports, we classified each problem within a research work unit as practical or theoretical. Practical research was defined as research that is directly applicable in the field; theoretical research is conducted primarily to provide a basis for further theoretical or practical research.

From the problem descriptions, publication titles, and narratives in the attainment reports, we also determined the distribution of benefits resulting from research. Most research work units address research problems of interest primarily to the region in which the station is located, but much research provides benefits to adjacent regions or to the entire nation. We noted three geographical regions in the attainment reports: (1) North (including the Midwest), (2) South, and (3) West (including the Pacific Northwest, Pacific Southwest, Alaska, and Hawaii). We also noted whether the research was national or international.

From the problem descriptions, we were also able to identify the organizations, companies, or landowners benefiting from a research program. Research problems were classified as benefiting all owners, public forest land owners, forest industry, or nonindustrial private forest land owners.

Forest Industries

Determining the level of investment in forest management research by forest industry was difficult without published information. Therefore, we surveyed landholding forest products companies to obtain estimates of the dollars spent and personnel employed in research on silviculture, biometrics and mensuration, genetics, and resource economics. Because of the difficulty in collecting the information, we requested estimates for fiscal year 1985 only.

For proprietary reasons, several companies declined to provide research budget figures. So, with the help of industry officials, we identified a small group of companies who invest significantly in forest management research. Through mail surveys and personal interviews, we obtained reliable data on their dollars and number of scientist-years invested in forest management research.

We also identified a group of 25 companies making smaller investments in forest management research than the first group and obtained data from 10 firms, which were representative in size and location. Sample responses were used to calculate average forest management research budgets and average scientist-years. Industry officials and research administrators indicated that the averages were appropriate for the industry. We expanded the averages from the 10 firms to estimate the total dollars and number of scientist-years invested in forest management research in this second group.

Universities

Universities constitute the third major sector conducting forest management research in the United States. We surveyed forestry schools at 47 universities to estimate the number of scientist-years allocated to four areas of forest management research in fiscal year 1985: (1) biometrics and mensuration, (2) the economic, financial, and legal aspects of forest management, (3) genetics, and (4) silviculture. Forty-four schools (or nearly 94 percent) returned usable responses. Responding schools included 11 out of 12 universities in the North Central region, 8 out of 8 in the Northeast, 15 out of 16 in the South, and 10 out of 11 in the West (regions correspond to those used by the National Association of Professional Forestry Schools and Colleges (NAPFSC)). We expanded the number of scientist-years provided by our responding schools by region to estimate scientist-years for all forestry schools in a region.

To determine the total investment in timber management research conducted by universities, we multiplied the number of scientist-years by an adjusted average cost per scientist-year. NAPFSC provides annual estimates of regional research funds by scientist-year (National Association of Professional Forestry Schools and Colleges 1986). This cost estimate includes funds directly appropriated to the schools as well as private and public research funds awarded to the schools. To avoid double counting, we adjusted the NAPFSC estimates to include only those funds directly appropriated to the schools, and we eliminated funding that would be accounted for in the Forest Service and industry totals.

Extent and Distribution of Forest Management Research

Results

We found that the three forestry sectors maintain a substantial program of forest management research. During fiscal year 1985, more than 660 scientist-years were involved in forest management research, resulting in investments of approximately $66 million. Notable differences exist among the research programs. Trends in funding and personnel, and the outlook for future research programs also differed.

Forest Service Research

The Forest Service is the largest forestry research organization in the United States. In fiscal year 1985, it employed about 800 scientists at 75 locations throughout the States, Puerto Rico, and the Pacific Trust Islands. The agency has more than 2,800 studies in progress at any one time (USDA Forest Service 1986). It also helps coordinate forestry research in the U.S. by cooperating with forest industries and by providing research funds to scientists in other research organizations (called extramural research). For example, in fiscal year 1985, the Forest Service funded 373 extramural research grants for a total of nearly $7.5 million (table 2).

Table 2.—*Forest Service extramural research, number of grants and funding, 1985 (USDA Forest Service 1986)*

Recipient	Number of grants	Thousand dollars
Domestic		
Universities and colleges	325	6,623
Federal, State, and local governments	20	315
Small business innovation research	11	302
Nonprofit institutions and organizations	8	149
Other domestic	6	74
Total domestic	370	7,463
Foreign grantees	3	15
Total	373	7,478

Table 3 summarizes the agency's forest management research efforts in terms of funding levels, number of personnel, and number of publications.

Research Funding.—Total funds allocated to forest management research increased in nominal terms from 1980 to 1985 but declined in real terms (fig. 3). The decline appears to be the result of a decline in the total Forest Service research budget rather than a shift in research priorities—between 1981 and 1986, forest management research consistently received 25 to 27 percent of the total research budget.

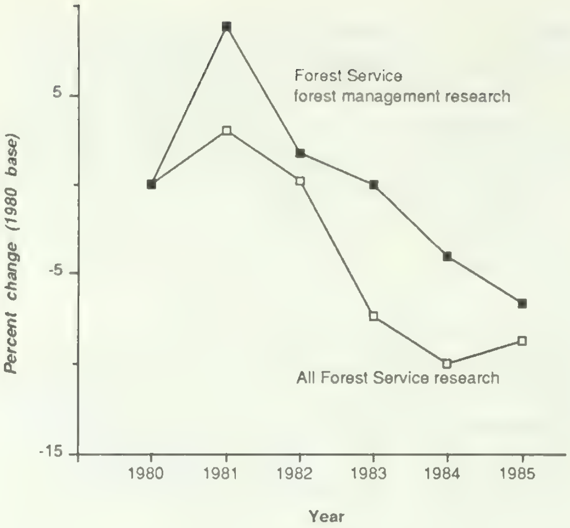


Figure 3.--*Percent change in the Forest Service research budget and the forest management research budget, 1980-1985 (USDA Research and Education Committee 1986).*

Funds for Forest Service forest management research flow from several accounts (called functional accounts) within the research budget. The Timber Management Research (TMR) functional account contributes the most forest management research funds, nearly 77 percent of the total annual budget (fig. 4). Several other functional accounts provide the balance of the forest management research budget, although none contributes more than 10 percent of the total. Although they contribute little to the forest management research budget, these other accounts fund research that is vital to the management of forest land.

Table 3.--*Inputs to and outputs from Forest Service forest management research, 1980-1985*

	Funding					
Year	Nominal	Real[1]	Total scientist-years	Funding/ scientist-year[1]	Total publications	Publications/ scientist-year
	(Thousand dollars)					
1980	24,180.0	24,180.0	275	88,007	518	1.9
1981	28,878.3	26,324.8	273	96,287	630	2.3
1982	28,707.6	24,595.1	268	91,876	533	2.0
1983	29,311.0	24,169.4	258	93,825	604	2.3
1984	29,213.7	23,207.3	250	92,848	641	2.6
1985	29,372.2	22,587.9	243	93,031	663	2.7
6-year average	28,277.1	24,177.4	261	92,646	598	2.3

[1] Real dollars, 1980 base.

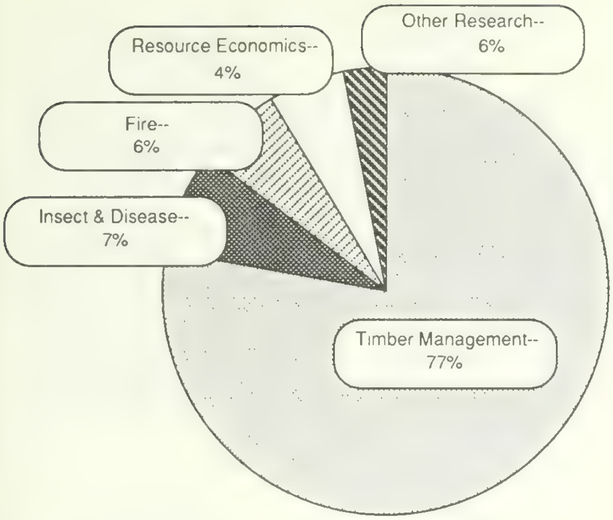


Figure 4.--*Average annual contribution of Forest Service functional accounts to the forest management research budget, 1980-1985.*

Figure 5 depicts the distribution of research funds among the four principal forest management research disciplines. Silviculture received the largest share of the annual budget, followed by genetics, economics, and mensuration. Several research disciplines shared the remaining forest management research budget, including hydrology, fire and atmospheric sciences, and wildlife management.

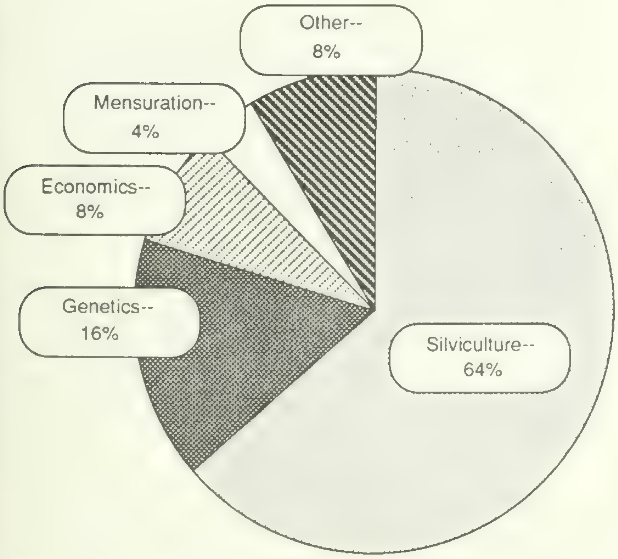


Figure 5.--*Average annual distribution of Forest Service forest management research funds among research disciplines, 1980-1985.*

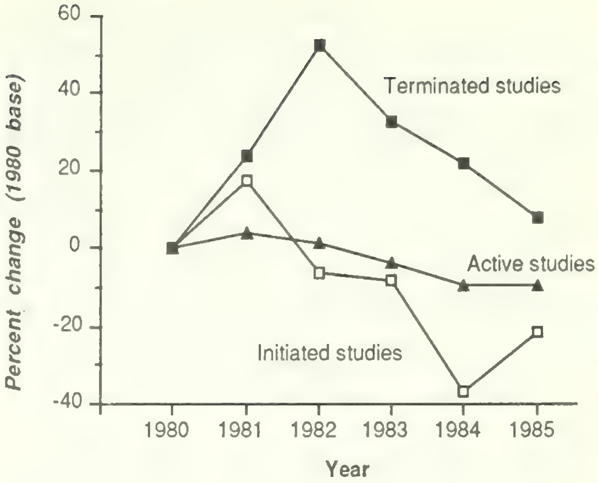


Figure 6.--*Percent change in the number of active, terminated, and initiated Forest Service forest management research studies, 1980-1985.*

Research Projects.—The annual attainment reports provided by each experiment station list the number and status of research projects for each work unit. In any given year, a project may be active, initiated, or terminated. Following a peak in fiscal year 1981, the number of studies has declined in each category in three of the four major research disciplines (fig. 6). Only genetics research has experienced a net gain in the number of initiated and active projects.

Staffing.—The number of scientists employed by the Forest Service in forest management research declined faster than the forest management research budget in each of the 6 years examined (fig. 7).

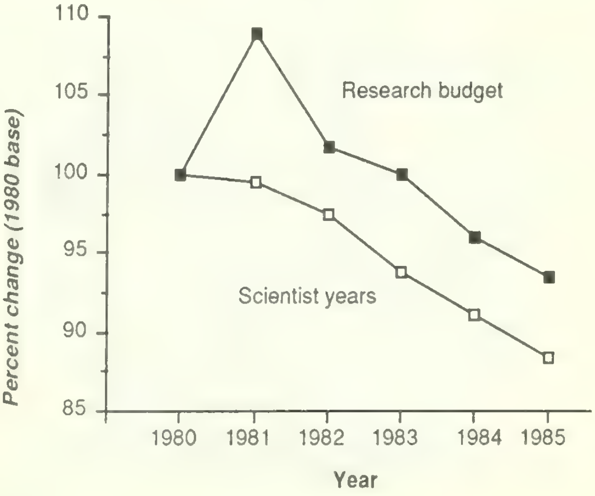


Figure 7.--*Percent change in scientist-years and budget for Forest Service forest management research, 1980-1985.*

The distribution of personnel among research disciplines was similar to the distribution of research funds, as would be expected. The relative order remained the same: silviculture employed the most personnel, followed by genetics, economics, and mensuration.

We used funding and personnel data to calculate funding per scientist-year for the 6 years. Nominal dollars per scientist-year increased annually; real dollars remained fairly stable (fig. 8). We found no pattern in funding per scientist-year for the four major disciplines. Silviculture research made up the largest portion of forest management research, so its yearly funding levels ($124,177 per scientist in 1985) had the greatest impact on the aggregate scientist-year funding estimates.

Publications.—Publications are the principal quantifiable output of the research process. The annual attainment reports list the total number of intramural and extramural publications and patents for each research work unit. Intramural publications are documents for which the research work unit claims senior authorship; extramural publications are those published by cooperators for which the work unit claims junior authorship or has contributed significant time, talent, and/or funds. The total number of publications for each year is shown in figure 9. In any one year, one-fourth of the publications are extramural.

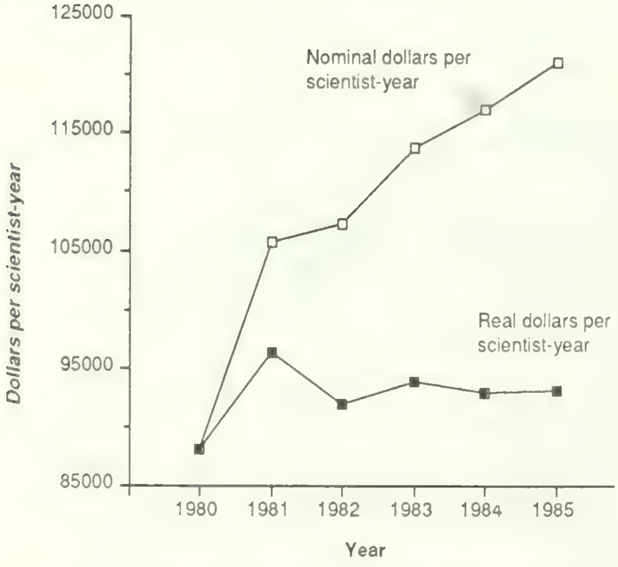


Figure 8.--*Trends in dollars per scientist-year for Forest Service forest management research, 1980-1985.*

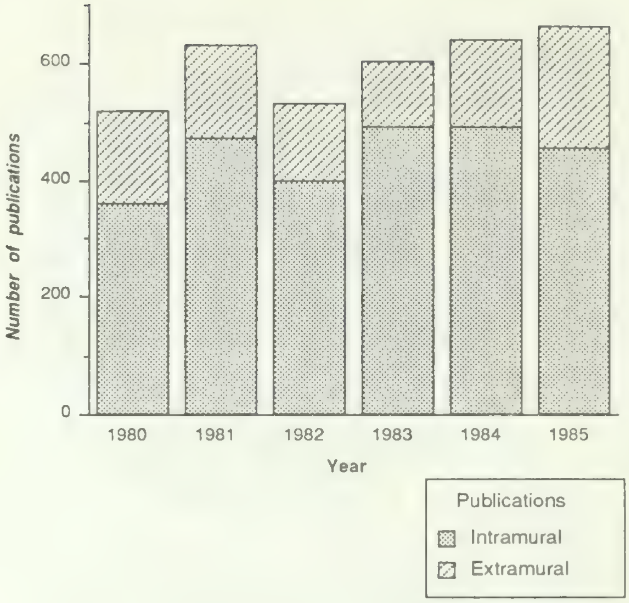


Figure 9.--*Number of intramural and extramural publications, Forest Service forest management research, 1980-1985.*

During the 6 years examined, the annual number of intramural publications rose by 27 percent and extramural publications increased by 31 percent. Similar increases have been found previously for Forest Service researchers. Jakes and Fege (1986) reported an 18-percent increase in the number of publications for the North Central and Northeastern Forest Experiment Stations between fiscal year 1980 and 1984. A more informative measure of research productivity is publications per scientist-year. Intramural publications per scientist-year averaged 1.7 during the 6 year period, extramural publications averaged 2.3. These rates compare favorably with other reported productivity ratios. Jakes (1985) reported a publication rate of 1.2 publications per scientist-year for all Forest Service researchers during fiscal years 1980 and 1981, noting that this was low because only senior-authored work was considered. The average 1980-1981 rate of senior-authored forest management publications (intramural and extramural) for those two fiscal years was 1.5 per scientist-year. Thus, on average, researchers in forest management appear to publish more than other Forest Service researchers.

The 6-year average publication rates for the four major disciplines were economics 2.0, genetics 1.9, silviculture 1.8, and mensuration 1.2 (table 4). Jakes (1985) also analyzed researcher productivity by research discipline, noting that geneticists averaged the most publications per scientist-year.

Table 4.—*Publications per scientist-year by research discipline, Forest Service forest management research, 1980-1985*

Year	Research discipline			
	Silviculture	Genetics	Economics	Mensuration
980	1.4	1.3	1.0	1.2
981	1.8	1.9	1.6	1.1
982	1.4	1.5	2.1	1.7
983	2.0	2.5	2.3	0.6
984	2.0	2.3	1.9	1.3
985	1.9	1.8	3.1	1.0
5-year average	1.8	1.9	2.0	1.2

Practical versus Theoretical Research.—Research s commonly classified by the nature of the research ffort or potential applications of research findings. O'Laughlin and his colleagues (1986) classed Forest Service research as productivity sustaining r productivity enhancing. They found that roductivity sustaining research received about 43 ercent of the Forest Service research budget, and roductivity enhancing research received the rest.

Most forest management work units conducted ractical research. On the average, more than 87 ercent of the annual forest management research udget supported practical research and 12.4 ercent supported theoretical research. Similar atterns existed in the allocation of personnel (87.3 ercent of scientist-years to practical, 12.7 to heoretical) and in publications (89.1/10.9).

Distributional Considerations.—We examined the istribution of Forest Service research funding mong geographical regions and ownership lasses. Because the distribution of scientist-years nd publications among geographic regions follows he distribution of funds, we will discuss only unding here.

lthough research findings clearly have significant pillover effects, we can still determine the region rimarily benefiting from a research project. Figure 0 depicts the average annual distribution of funds mong the three geographic regions examined North, South, and West), as well as among ational and international clients.

s might be expected, forest management research unds were concentrated in the areas of intensive mber management. Research work units ddressing western or southern forest management roblems accounted for an average of more than 66 percent of the research funds. Most western funds were concentrated on projects involving the major timber producing areas of California, Oregon, and Washington. Most southern funds were allocated to projects focusing on the management of the economically important southern pines, although a large portion was spent on hardwood management research. Research projects addressing forest management in the Northeast annually received about one-quarter of the total forest management budget. An average of 7 percent of the total budget was directed to projects that involve all regions, and 4 percent had international applications.

We also classified the forest management research variables according to the ownership classes benefiting from the research. Research inputs and outputs were classified as applying to all owners, or to one or two of the following: government, industry, and/or nonindustrial private.

Nearly half of the research funds supported research benefiting all owners (fig. 11). Public owners benefited from more than 90 percent of the Forest Service forest management research (including research benefiting all owners). From fiscal year 1980 through fiscal year 1983, industrial forest managers benefited from the second largest share of funds. Beginning with a high of 82.7 percent in fiscal year 1980, industry's share of research funds declined to 62.0 in fiscal year 1984. In contrast, research benefiting NIPF's increased steadily from fiscal year 1982, and received the second largest share of funds in fiscal years 1984 and 1985.

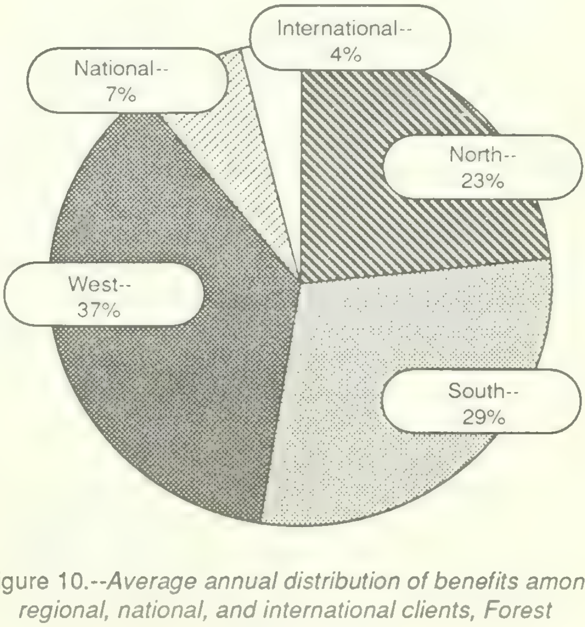


Figure 10.--*Average annual distribution of benefits among regional, national, and international clients, Forest Service forest management research, 1980-1985.*

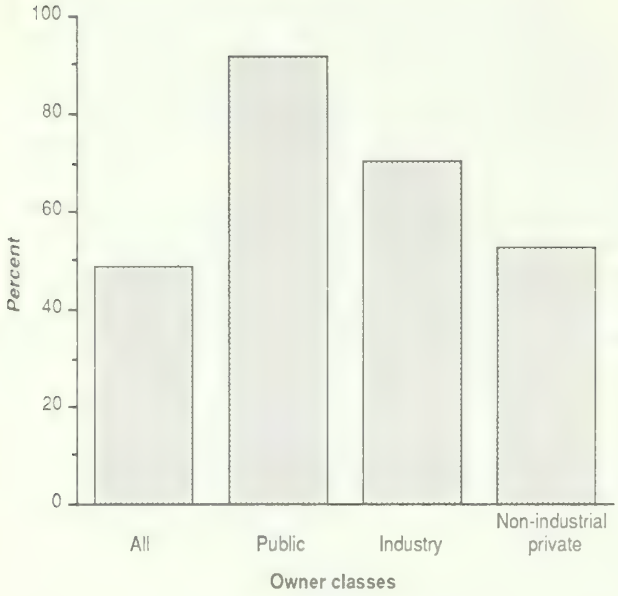


Figure 11.--*Average percent of research benefiting owner classes, Forest Service forest management research, 1980-1985.*

Forest industries

The forest management research effort by forest industry has declined significantly in the past 15 years. To cut corporate costs during the recession of the late 1970's and early 1980's and also to avoid corporate takeovers, industry managers have taken actions to improve short-term profits. As a result, research departments have been severely reduced. Most companies have made significant cuts; others have eliminated substantial forest management research efforts. Giese (1987) reports estimates by the American Forest Council that place the reduction in forest industry research between 30 and 50 percent since the early 1980's.

The remaining industrial forest management research consists largely of field tests to apply existing technology to the companies' specific situations. This is being conducted primarily by in-house researchers or through industry-university research cooperatives. The bulk of this work has involved investigations of site preparation techniques, tree improvement, and vegetation control. Predictably, most industrial research is done in the South and West.

As mentioned earlier, a few companies conduct most of the current industrial forest management research. In fiscal year 1985, these firms invested about $9.7 million in forest management research projects requiring 90 scientist-years.

The 25 firms conducting more limited forest management research programs invested an estimated $9.7 million and approximately 87 scientist-years. The averages for the reporting firms equaled $388,400 and 3.5 scientist-years per firm. Adding these estimates to the figures reported by a few major research firms results in a total forest management research effort by industry of about $19.4 million and 177 scientist-years—or $109,400 per scientist-year. Because much of the information produced by industry research is proprietary and because the few publications produced provide a poor gauge of research productivity, we do not discuss productivity measures for industry research here.

Universities

Forest management research constitutes a major portion of all research conducted at forestry schools throughout the United States. These schools perform most basic research pertaining to forest management, although they conduct much practical research as well. Similar to Forest Service and industry research, most university forestry research is conducted in the regions of intensive forestry.

The 44 schools responding to our survey reported 226 scientist-years conducting forest management research. We expanded this finding to represent 242 total scientist-years for all university forest management research programs. The largest number of university researchers, both nationally and regionally, were conducting silvicultural research (table 5). Nationally, economics research employed the second largest number of researchers, followed by biometrics/mensuration and genetics. These trends hold for all regions, except the North Central United States, where genetics research is more prevalent than biometrics/mensuration.

In all, universities spent more than $17 million in State and Federal funds on forest management research. Of the $17 million, almost one-half was spent in the South ($7.9 million), and about $3.5 million was spent in each of the West and North Central regions. An additional $14 million derived from non-appropriated sources such as grants, timber sales, or other sources was also spent on university forest management research.

Of course, all the schools reporting did not necessarily conduct research in each forest management research discipline—certain universities within a region specialize in specific

Table 5.—*Number of scientist-years invested in forest management research at U.S. forestry schools responding to the survey, 1985*

Region	Respondents/ total number of schools	Research discipline			
		Silviculture	Genetics	Economics	Mensuration
North Central	11/12	20.0	9.9	11.5	9.0
Northeastern	8/8	11.3	6.0	7.8	7.3
South	15/16	34.6	17.0	18.8	16.4
West	10/11	17.8	4.6	20.7	13.5
Total	44/47	83.7	37.5	58.8	46.2

disciplines. Research cooperatives provide a good example of this concentration—North Carolina State University has a major cooperative in genetics, the University of Georgia's Plantation Management Research Cooperative emphasizes growth and yield modeling, and the University of Washington's Regional Forest Nutrition Research Program is one of the oldest cooperatives in the West. A recent survey estimated that these research cooperatives represent $5.4 million and 53 scientist-years of forestry research (American Forest Council 1986). As a result, some individual schools accounted for one-half of the total regional scientist-years reported in table 5.

Discussion

Research Funding

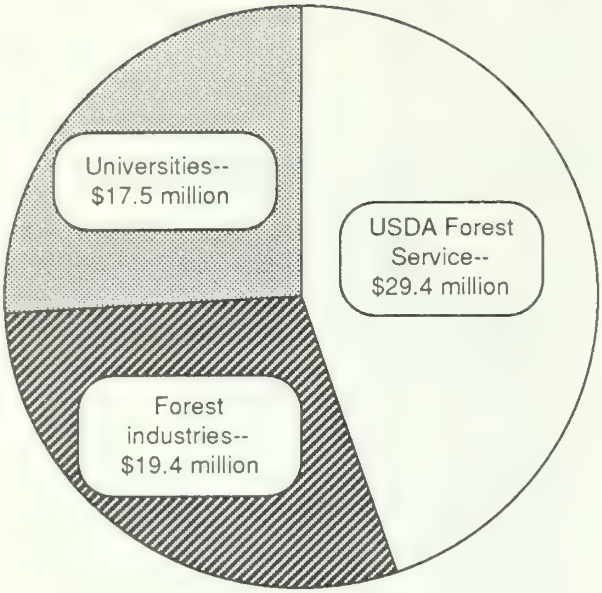
Figure 12 summarizes the forest management research funding and personnel for each of the three major forestry research sectors. Together, the three expended approximately $66 million in 1985 on forest management research requiring more than 660 scientist-years. These totals should be conservative, as only direct State and Federal appropriations to university research were considered. A similar survey of Forest Service and university forestry research in the South supports this study's estimates. The Southern Industrial Forestry Research Council (SIFRC) (1986) estimated that total forestry research in the South involved 310.8 scientist-years and $39.9 million in 1985. The SIFRC found that forest management research in the South involved 143 scientist-years and $17.5 million. The regional results of our study indicated that 166.5 scientist-years and $18.1 million were involved in southern forest management research.

Real dollars appropriated for all Forest Service research, and specifically forest management research, have declined since fiscal year 1981. Scientist-years for forest management research declined in each year we examined. The decline in industrial forest management research has been even greater; many major companies have even dismantled entire forestry research departments. Although no data were collected to determine trends in university research, it is likely that this sector may reduce its research effort as well, if it has not already done so. Declining student enrollment, reduced Forest Service extramural funds, and shrinking industry research funds probably have forced some cutbacks in research personnel. Two bright spots may be an increased industry reliance on universities to perform some of the research that the companies have traditionally conducted themselves, and the availability of funds in various competitive grant programs. Still, the net impact over all sectors has been a decline in research funding and personnel.

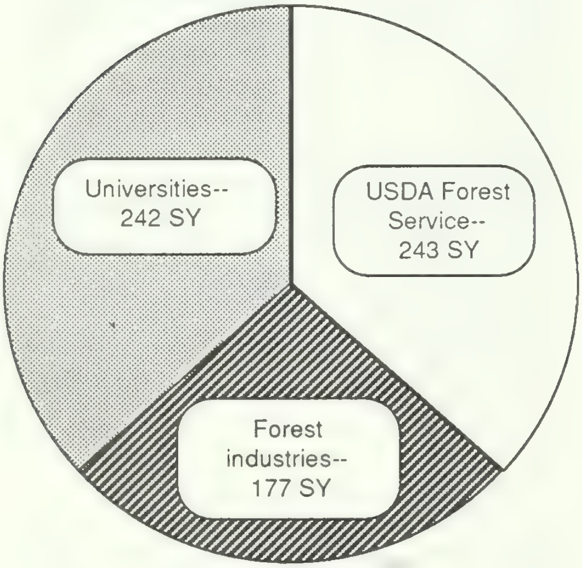
Productivity

The trends in research productivity may differ substantially from those described for funding and personnel. Because we calculated productivity measures for Forest Service researchers only, this discussion deals with trends in only that agency's forest management research productivity. However, much of academia is facing pressure to be more productive, both in research and teaching, while industrial research administrators are often asked to maintain the present level of productivity with reduced resources. Therefore, the trends observed within the Forest Service may be similar to those of all forest management research organizations.

Publications per Forest Service scientist-year in forest management research have increased significantly, as described earlier. Although they declined during the last year we examined, the publications per scientist were still 42 percent higher



a. Distribution of the $66 million U.S. forest management research effort among participants



b. Scientist-years contributed to the U.S. forest management research effort

Figure 12.--*Funding and personnel invested in U.S. forest management research by participant, 1985.*

than during the first year we examined. These figures suggest that the written productivity of those scientists conducting forest management research has greatly improved. Average figures may be misleading, however, Jakes found that in fiscal years 1980 and 1981, 20 percent of all Forest Service researchers produced 58 percent of all senior-authored agency publications. A similar ratio for forest management research in 1985 would imply that 49 scientist-years were responsible for 264 publications—a publication ratio of 5.4 per scientist-year. Although this cannot be determined with current data, it shows the potential variability in researcher productivity.

We must note that the number of publications provides only an indication of true research productivity. The productivity of any research effort must be based on its ultimate impact on the resource and its users. Numerous factors are involved in determining the impact of forest management research. Of particular significance are factors affecting the degree and rate of the adoption of research findings. The importance of these factors may differ by owner and region. For example, altering the pattern of adoption may be crucial to enhancing the utility of forestry research in the South, where most timberland is owned by individuals who traditionally have been slow to adop new management practices. Conversely, forest management research findings may be adopted quickly where the major land holders are large fores products companies or the Forest Service. Therefore, the entire research and technology transfer process must be understood before the impact, or productivity, of forest management research can be calculated—a much more complex effort than counting publications.

Distributional Factors

Several issues are involved in the distribution of research resources and benefits. This study examined how the resources and products of Forest Service forest management research were distributed among geographic regions and ownership classes. We can consider several additional issues concerning the distribution of benefits from public forest management research.

The distribution of forest management research funding and personnel by geographic region suggests that they are allocated in an economically rational manner. Most research funds and personnel were committed to those areas of intensive forestry—the South and major timber regions of the West—where return to research investments should be the greatest. Another issue in the regional distribution of research resources and benefits concerns the equity of the distribution. Although favoring more productive regions may be economically efficient, the resulting distribution may not be completely equitable. Allocating most resources to the South may preclude developing innovations in the Northeast that would make it a more competitive supplier of forest products. Examples of "regionally biased" innovations include genetically superior southern pine seedlings and mproved site preparation techniques for southern orest management.

The efficiency and equity of the distribution of esources and publications among ownership classes are difficult to quantify. Bengston and Gregersen (1986) note that the two most important actors in determining the distribution of research benefits among large (in this instance industry and, o a lesser extent, government) and small (NIPF) producers are innovator's rent and the scale bias of new technologies. Inventor's rent refers to the emporary advantages early adopters of a new echnology receive because they have lower production costs than late adopters. Industry probably receives innovator's rent on most forest management innovations because it normally adopts such new technologies earlier than NIPF andowners. Bengston and Gregersen (1986) urther note that innovator's rent may be the only benefit for producers if the commodity has an nelastic demand and adoption is widespread. Scale bias occurs when a new technology benefits primarily large producers, with little or negative mpact on small producers.

The distribution of benefits between producers and consumers was not explicitly covered in this study. However, some conclusions can be drawn based on previous work on this area. Bengston and Gregersen (1986) note that the main determinant of the distribution between producers and consumers is the price elasticity of demand for the commodity in question. Consumers benefit most from research on those commodities with inelastic demands; producers receive the most benefits from research conducted on commodities with elastic demands. Given the inelastic demand for most primary wood products, consumers (e.g., forestry industry) should capture the bulk of benefits arising from forest management research. Newman (1986) found that consumers of southern solidwood markets receive 90 percent of the total benefits of technical change, but 150 percent of the total benefits of technical change in southern pulpwood markets. Thus, Newman observes that NIPF landowners are unlikely to adopt research findings because they gain little from such innovations. One way to increase NIPF productivity, therefore, is through use of subsidies. In contrast, forest products firms will adopt new technology because the benefits they do not receive as producers will be recaptured through reduced prices for raw materials for their processing plants.

Two additional issues identified by Bengston and Gregersen (1986) concern the distribution of benefits among labor and capital between generations. Stier (1980) found that technological change in eight U.S. forest products industries was labor-saving. Similar results are likely for most forest management innovations, because the work force involved in forest management has probably declined significantly in the past 25 years.

Finally, forest management research benefits are probably distributed evenly among the present and future generations. Numerous forest management research topics, such as financial and legal considerations of forestry, provide immediate benefits. Conversely, other research, specifically biological research on tree species with long growing periods, provides benefits to future generations (Bengston and Gregersen 1986).

Conclusions

Forest management research is a big part of forestry research in the United States. In 1985, the Forest Service invested nearly $30 million in forest management research, forestry industry invested $19 million, and universities invested at least $17 million. Investments in this research, however, have been declining since then. Forest Service funding has decreased modestly in real terms, and total industry research has decreased drastically in nominal and real terms. University forest management research budgets have probably declined in many States because of State budget shortfalls or declining forestry school enrollments (and university budget payments). However, some other schools have increased research funds substantially in recent years. Total university research budgets have probably maintained their real funding levels in the 1980's. Continuing to do so in the future, with consistently low student enrollment levels, may be difficult.

Although budget and personnel levels for forest management research are apt to decline, productivity is likely to increase. In the face of budget and personnel reductions, the remaining Forest Service researchers undoubtedly feel more pressure to justify their existence through publishing. Industry researchers, too, will certainly want to demonstrate to their corporations the value of their research to the bottom line. Academic researchers are also likely to feel increasing pressure to perform and publish as student enrollments wane. Most university systems have more tenured faculty but fewer students. These factors will undoubtedly lead to stricter promotion and tenure standards, which will spur greater productivity by all faculty.

The distribution of research benefits by Forest Service researchers indicates that the public sector is the largest beneficiary, being able to use more than 90 percent of the forest management research. Forest industry and the nonindustrial private forest sector are the intended beneficiaries of about 70 percent of Forest Service forest management research. Industry research is designed primarily for their own use, but probably much of their contributions to university cooperatives may be published in a form useful for public and NIPF owners. Data are not available on the beneficiaries of university research. Certainly one might expect that the NIPF sector and forest industry sectors, which pay taxes for State budgets, would be the principal beneficiaries.

In the United States, the Pacific Northwest and the South received the greatest share of Forest Service and industry forest management research benefits. This seems logical, because these two regions account for at least two-thirds of the U.S. timber harvests and values. They also had the largest amount of university research, followed closely by the North Central region. The Northeast region, whose predominantly hardwood forests are less valuable for timber and less profitable to manage intensively, might be expected to have less forest management research.

This overview of United States forest management research has shown that the Forest Service contributes the most to forest management research in terms of annual budgets and scientists employed. Its research efforts are dwindling, however, due to budget constraints. Industry research has declined even more, while universities have remained stable, at least to date. Our challenge is to justify and obtain the level of funding necessary for a forestry research program that addresses the Nation's needs.

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In 1985, the USDA Forest Service invested nearly $30 million in forest management research, forest industry invested $19 million, and universities invested at least $17 million. Investments in this research have been declining since then. Forest Service data indicate that the public sector is the largest beneficiary of forest management research.

KEY WORDS: Research investments, research benefits, forest management research.

FINDING OUT AND TELLING

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it--in short, "finding out and telling." As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL
FOREST
EXPERIMENT STATION

United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report **NC-127**

The Microcomputer Scientific Software Series 5

The BIOMASS User's Manual

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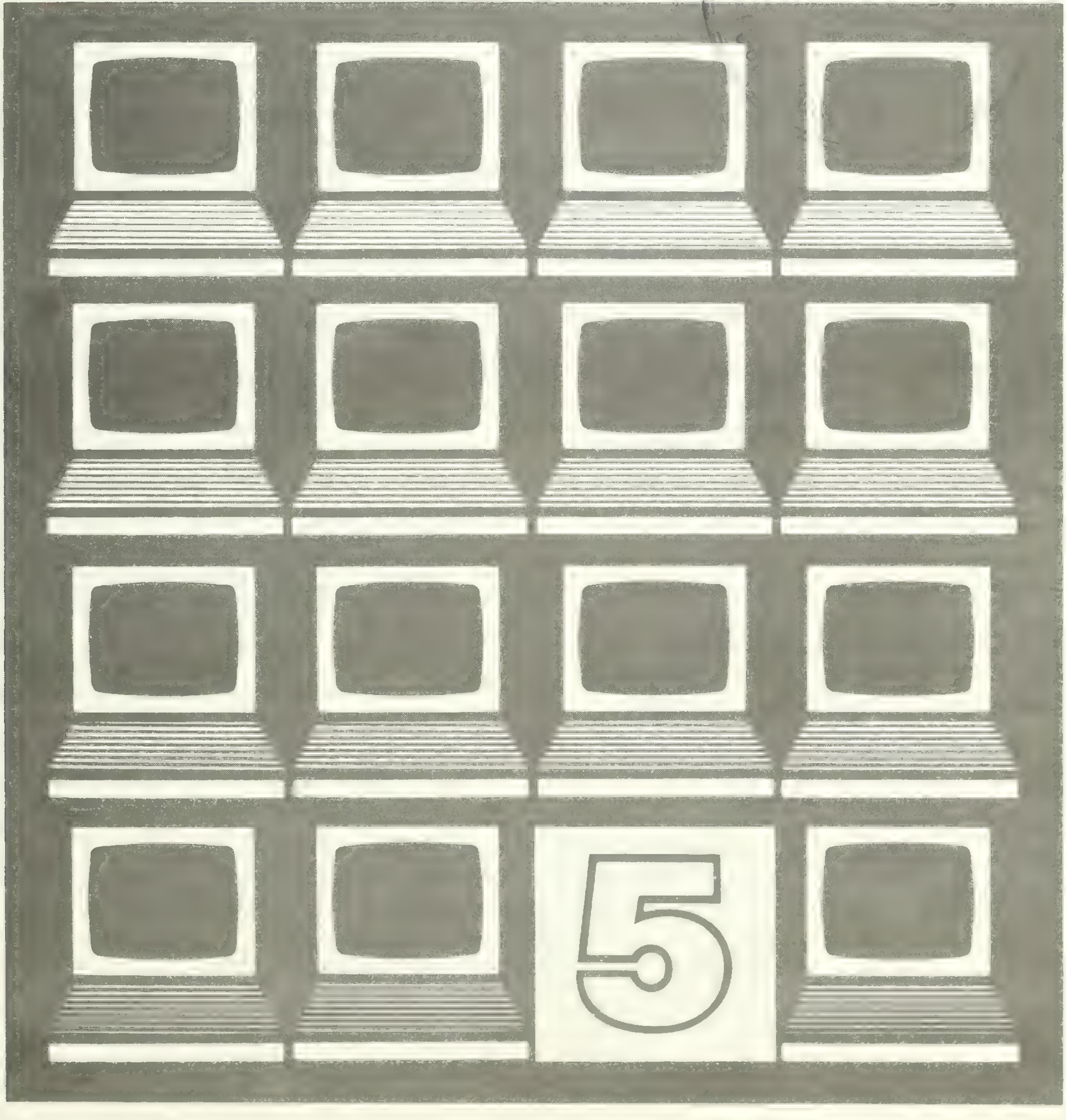

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The Microcomputer Scientific Software Series 5: The BIOMASS User's Guide

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Introduction

The increased interest in complete tree utilization and the need for biomass estimates in ecological research have resulted in the development of species-specific biomass equations for most important tree species of the Lake States. BIOMASS is an interactive microcomputer program that calculates total aboveground biomass for major tree species of the Lake States using these published equations. Biomass equations use diameter or a combination of height and diameter to predict oven-dry weight of entire trees or tree components. The methods used to sample trees and develop biomass equations are reviewed in Hitchcock and McDonnell (1979), Tritton and Hornbeck (1982), and Crow and Schlaegel (1988).

Biomass Equations

In developing BIOMASS, we attempted to select the most appropriate equations available for important overstory species of the Lake States. Factors important in selecting the equations were (1) the independent variables used, (2) the geographic area in which the equations were developed, (3) the sample size and range of diameters used to develop the regression functions, and (4) the correlation coefficient or standard error of the estimate for the equation. Equations that use only diameter as an independent variable are generally reliable only in the local area in which they were developed. Equations using both diameter and height incorporate the effect of site quality into the function and are therefore applicable on a regional basis (Young 1976, Schmitt and Grigal 1981). Generalized biomass equations, which have been proven reliable over a wide geographic range, are acceptable even if height is not included (Grigal and Kernik 1984). Most of the equations used in BIOMASS are driven by height and diameter or are generalized equations, and should be applicable over most of the North Central region.

Equations developed using regression analysis are valid only within the diameter range of the trees used to construct the regression. Extrapolating beyond the range of the data used to develop the equation can result in substantial error. BIOMASS will calculate estimates outside the diameter range but will flag these values with an error code. The user must interpret these estimates cautiously.

General hardwood and softwood biomass equations (Monteith and Jacobs 1979) were included in the program to accommodate species for which biomass equations are currently unavailable, such as cottonwood, silver maple, black ash, and elm.

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Table 1.—*Biomass equations, regression coefficients, sources, and related information*

Species	Equation	r^2	Diameter range (cm)	Location	Units (Y,D,H)[1]	Source
Balsam fir (*Abies balsamea* (L.) Mill.)	Y =0.018308*D^2*H+0.000717*D^2*H (whole tree + dead branches)	0.98	5.7 - 27.4	ONTARIO	kg,cm,m	Alemdag 1982
Tamarack (*Larix laricina* (Du Roi) K. Koch)	log Y = 0.4065+2.298*log D	.98	7.6 - 30.2	MN	lb,in	Carpenter 1983
White spruce (*Picea glauca* (Moench) Voss)	Y = 0.018219*D^2*H+0.001012*D^2*H (whole tree + dead branches)	.97	6.3 - 35.8	ONTARIO	kg,cm,m	Alemdag 1982
Black spruce (*Picea mariana* (Mill.) B. S. P.)	Y = 0.153*D^2.248	.98	3.0 - 30.0	MN	kg,cm	Grigal & Kernik 1984
Jack pine (*Pinus banksiana* Lamb.)	Y = 0.0726*D^2.091*H^0.435	.99	2.8 - 32.8	Lake States	kg,cm,m	Green & Grigal 1978
Red pine (*Pinus resinosa* Ait.)	Y = 0.03556*D^1.8869*H^0.8693	.99	10.4 - 27.2	MN,MI,WI	kg,cm,m	Alban & Laidly 1982
Eastern white pine (*Pinus strobus* L.)	Y = 0.5209+0.07434*D-0.5439*H + 0.0001516*D^2*H	.98	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Northern white-cedar (*Thuja occidentalis* L.)	ln Y = -2.3939+1.8187*ln D+0.4796*ln H	.99	2.2 - 30.2	New Brunswick	kg,cm,m	Ker 1980
Eastern hemlock (*Tsuga canadensis* (L.) Carr.)	Y = 1.4081+0.1824*D-1.4563*H+ 0.0001842*D^2*H	.99	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Red maple (*Acer rubrum* L.)	ln Y = -1.545+0.923*ln (D^2*H)	.97	10.0 - 52.2	Lake States	lb,in,ft	Crow & Erdmann 1983
Sugar maple (*Acer saccharum* Marsh.)	Y = 0.06116+0.1752*D-0.8988*H+ 0.0002761*D^2*H	.99	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Yellow birch (*Betula alleghaniensis* Britton)	Y = -4.9178+0.02462*D+0.5461*H+ 0.0002773*D^2*H	.98	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Paper birch (*Betula papyrifera* Marsh.))	Y = 0.0501*D^2.301*H^0.417	.99	0.0 - 29.5	Lake States	kg,cm,m	Schmitt & Grigal 1981
Hickory (all) (*Carya* spp. Nutt.)	Y = 0.10308*(D^2*H)^1.01605	.99	5.1 - 40.6	WV	lb,in,ft	Wiant *et al.* 1979
American beech (*Fagus grandifolia* Ehrh.)	Y = 0.78331+0.08899*D-0.529705*H+ 0.0002996*D^2*H	.97	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
White ash (*Fraxinus americana* L.)	Y = -4.17764+0.21947*D-0.44212*H+ 0.000204*D^2*H	.99	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Yellow-poplar (*Liriodendron tulipifera* L.)	Y = 0.07599*(D^2*H)^0.99425	.99	5.1 - 40.6	WV	lb,in,ft	Wiant *et al.* 1979
Quaking aspen[2] (*P. tremuloides* Michx.)	ln Y = 0.98996(ln D^2*0.00545*H)+2.7422	.99	5.1 - 33.0	MN	lb,in,ft	Schlaegel 1975
Black cherry (*Prunus serotina* Ehrh.)	Y = 0.12968*(D^2*H)^0.97028	.99	5.1 - 40.6	WV	lb,in,ft	Wiant *et al.* 1979
White oak (*Quercus alba* L.)	Y = 0.08782*(D^2*H)^1.0206	.99	5.1 - 40.6	WV	lb,in,ft	Wiant *et al.* 1979
Northern red oak (*Quercus rubra* L.)	Y = 9.68288+0.42137*D-4.16579*H+ 0.000265*D^2*H	.99	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
Black oak[3] (*Quercus velutina* Lam.)	Y = 0.14206*(D^2*H)^0.97268	.99	5.1 - 40.6	WV	lb,in,ft	Wiant *et al.* 1979
American basswood (*Tilia americana* L.)	Y = 1.4416*D^2.5328	.96	6.3 - 50.8	WV	lb,in	Brenneman *et al.* 1978
General hardwood	Y = 0.31666+0.04666*D-0.2082455*H+ 0.0002549*D^2*H	.96	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979
General softwood	Y = 1.57734+0.13039*D-1.21916*H+ 0.0001774*D^2*H	.90	2.5 - 55.0	NY	kg,mm,m	Monteith & Jacobs 1979

[1] Y = oven-dry mass, D = diameter at breast height, and H = height.

[2] equation also used for Bigtooth aspen, (*Populus grandidentata* Michx.)

[3] equation also used for Northern pin oak, *Quercus ellipsoidalis* E. J. Hill

Outputs from the general equations are flagged. New biomass equations may be added to the program as they become available.

Most of the equations used in BIOMASS were developed in the Lake States area. In some cases, equations from this region were not available, so biomass equations developed in other parts of the eastern United States and Canada were used. Efforts were made to ensure that these equations included height as an independent variable. The equations used by BIOMASS, their regression coefficients, diameter ranges, correlation coefficients, and sources are presented in table 1. Nomenclature for overstory species follows Little (1979).

Field Sampling

BIOMASS is designed to handle standard timber cruise data collected from fixed area or variable radius (point) sample plots. Average plot heights and diameters may also be used. BIOMASS operates at the stand level, and assumes that one or more plots/points have been sampled per stand. The program uses English units for data input: diameter at breast height in inches and total height in feet. Species are coded using the standard Forest Service three digit coding system (USDA Forest Service 1972). BIOMASS will generate tree, plot, and stand level summaries, in either English or metric units.

Program Overview

The BIOMASS program comprises three major sections: an input routine that controls data entry and file organization, a calculation routine that processes the input data, and an output routine that expands the data to an areal basis and controls the screen and printer outputs. Data may be entered from the keyboard or read from an existing disk file. The program is interactive and menu-driven, consisting of BIOMASS INPUT and OUTPUT Menus and several data entry screens. In addition to screen and printer output, BIOMASS can create disk files that summarize the input data at the individual tree, species, or plot level. The disk files are compatible with most statistical and report-generating software.

Program Setup and File Structures

Hardware Requirements

BIOMASS has been written and compiled using Microsoft QuickBASIC V 4.0. The program runs under MS-DOS on both floppy disk and hard disk-based systems. Both color and monochrome monitors are supported. A printer is needed for printer reports but not for program operation.

Installation

To install BIOMASS on a hard disk, simply copy the four BIOMASS program files (BMASS.EXE, BIOMASS.LIB, VIDPOP.COM, and BIOMASS.BAT) to a subdirectory on the hard disk. We recommend storing all program and data files in a single subdirectory.

File Structures

BIOMASS creates two disk files to store the input data and stand description information, and generates up to three summary files. These files may be stored on the program disk or written to a separate disk. All files associated with a given stand use the same filename but with different extensions (table 2). The user supplies a single filename (up to eight characters in standard DOS format); BIOMASS adds the appropriate extensions. The DOS user's manual includes further information on naming files.

Table 2.--Example input and output files created by BIOMASS

REDCEDAR.DES	the stand description file (input)
REDCEDAR.INP	the input data file (input)
REDCEDAR.SUM	the individual tree biomass file (output)
REDCEDAR.SP	the species-level summary file (output)
REDCEDAR.PL	the plot-level summary file (output)

Caution: If the user specifies a filename that already exists, **the previously stored files will be erased !**

The BIOMASS files are described below:

The Stand Description File

The stand description file stores the basic sampling information, and is created when new stand data are entered. Information stored in this file includes the stand name and location, sampling method (fixed or variable plots), plot size or basal area factor (BAF), crew, date, number of plots sampled, and maximum number of trees on a plot. The stand description file has the filename extension **DES**.

A typical stand description file is as follows:
"Red Cedar 1","T4N R1W Sec. 22","F",.1,"Cole, Zak","4/1/85",3,9

This stand was sampled using three fixed area plots, each 0.1 acre in size, with a maximum of nine trees on any plot.

The Input Data File

The input data file contains the information associated with individual sample trees. Input data files have the file extension **INP**. Sample data may be entered through the BIOMASS data input routine, or read into the program from an external data file (see below). Each line of the file contains data for one sample tree; these data are the plot number, the numeric species code, diameter at breast height (d.b.h.) in inches, and total tree height in feet. Plots are stored in sequential order.

An input data file may be created by a text editor, word processor, or a previous run of BIOMASS. The file must have the filename extension **INP**, e.g. REDCEDAR.INP. The file must be in comma or space-delimited ASCII format, with no special formatting or control characters. Each line must consist of individual tree data in the following order:

plot number, species code, d.b.h. in inches, total height in feet.

The file must be sorted by increasing plot numbers. The following are two example input data files:

```
COMMA-DELIMITED              SPACE-DELIMITED
    FORMAT                       FORMAT

  1,316,12.5,56          1    316      12.5    56
  1,743,15,71            1    743      15.0    71
  2,837,8,38             2    837       8.0    38
  2,802,10.8,54          2    802      10.8    54
  2,802,7,38             2    802       7.0    38
  3,125,6.0,32           3    125       6.0    32
  3,129,12.0,41          3    129      12.0    41
  3,12,14.0,61           3     12      14.0    61
  3,74,8.0,42            3     74       8.0    42
```

The Output Files

The input data files are read into the calculation routine of BIOMASS. The species codes are used to transfer the height and diameter data to the appropriate biomass equations. The calculated biomass values are then written to a summary file, which has the extension **SUM**.

The summary file is a fixed-format ASCII file containing the raw input data and the calculated biomass values in metric and English units. The columns of the summary file are as follows: plot number, species code, diameter in inches, diameter in centimeters, height in feet, height in meters, aboveground dry weight in pounds, aboveground dry weight in kilograms, and an error code. An example of the summary data file is shown below:

```
1  316   12.5   31.8   56   17   928   421   0
1  743   15.0   38.1   71   22  1291   586   1
2  837    8.0   20.3   38   12   279   127   0
2  802   10.8   27.4   54   16   662   300   0
2  802    7.0   17.8   38   12   191    87   0
3  125    6.0   15.2   32   10    97    44   0
3  129   12.0   30.5   41   12   424   192   0
3   12   14.0   35.6   61   19   986   447   1
3   74    8.0   20.3   42   13   303   138   0
```

The error codes denote biomass values that have been extrapolated beyond the range of diameters used to develop the equation or that have been calculated from the general hardwood or softwood equations. The error codes are interpreted as follows:

1 —Diameter beyond range of equation
2 —General hardwoods equation used
3 —General softwoods equation used
4 —Diameter beyond range of a general equation
5 —Unknown species code, general hardwood equation has been used

The user should again be cautioned that interpretation of data from beyond the range of the regression or from general equations may be subject to error. The magnitude of the error depends on the extent of extrapolation and the reliability of the equations.

In addition to the summary file, two other output files may be written to disk. These files are created by choosing Option 2 (View Plot-level Expansion) from the BIOMASS OUTPUT MENU. The species-level output file summarizes biomass data by plot and species. This file has the extension **SP**. The four columns of the species-level summary are plot number, species code, biomass in lb/ac, and kg/ha, respectively:

```
1      316      9280      10440
1      743     14120      15885
2      802      8530       9596
2      837      2790       3139
3      125      4450       5006
3      129      8230       9259
3       12       950       1069
3       74      3030       3409
```

The plot-level output file (extension **PL**) summarizes total biomass by plot. The three columns of this file are the plot number, and biomass in lb/ac, and kg/ha, respectively:

```
1         23400          26325
2         11320          12735
3         16660          18743
```

Using the Program

Starting the Program

BIOMASS is started by typing **BIOMASS** at the DOS prompt. The BIOMASS batch file installs the screen management utility and runs the BIOMASS program. An opening screen is displayed and after a few seconds the BIOMASS INPUT MENU appears.

Entering Biomass Data - The BIOMASS INPUT MENU

The BIOMASS INPUT MENU controls data entry and disk file management. The options for this menu are as follows:

1) Enter New Individual Tree Data For Variable Radius Plots
2) Enter New Individual Tree Data For Fixed Area Plots
3) Enter Average Plot Heights and Diameters - Variable Radius Plots
4) Enter Average Plot Heights and Diameters - Fixed Area Plots
5) Use an Existing File / List Files
6) Exit BIOMASS

An option is selected by typing the number of the option or by pointing to the option with the highlight and pressing the return (Enter) key.

Entering Data from the Keyboard - Options 1-4

Options 1 to 4 allow the user to enter data from the keyboard. The user will be asked to specify a disk drive (A-E) and a file name (up to eight letters; e.g. REDCEDAR). BIOMASS will append the appropriate file extensions to this name. The user is then presented with a screen for entering the stand description data. The screen contains the following fields:

Stand name
Stand location
Plotsize / BAF
Number of plots
Crew names
Sampling date

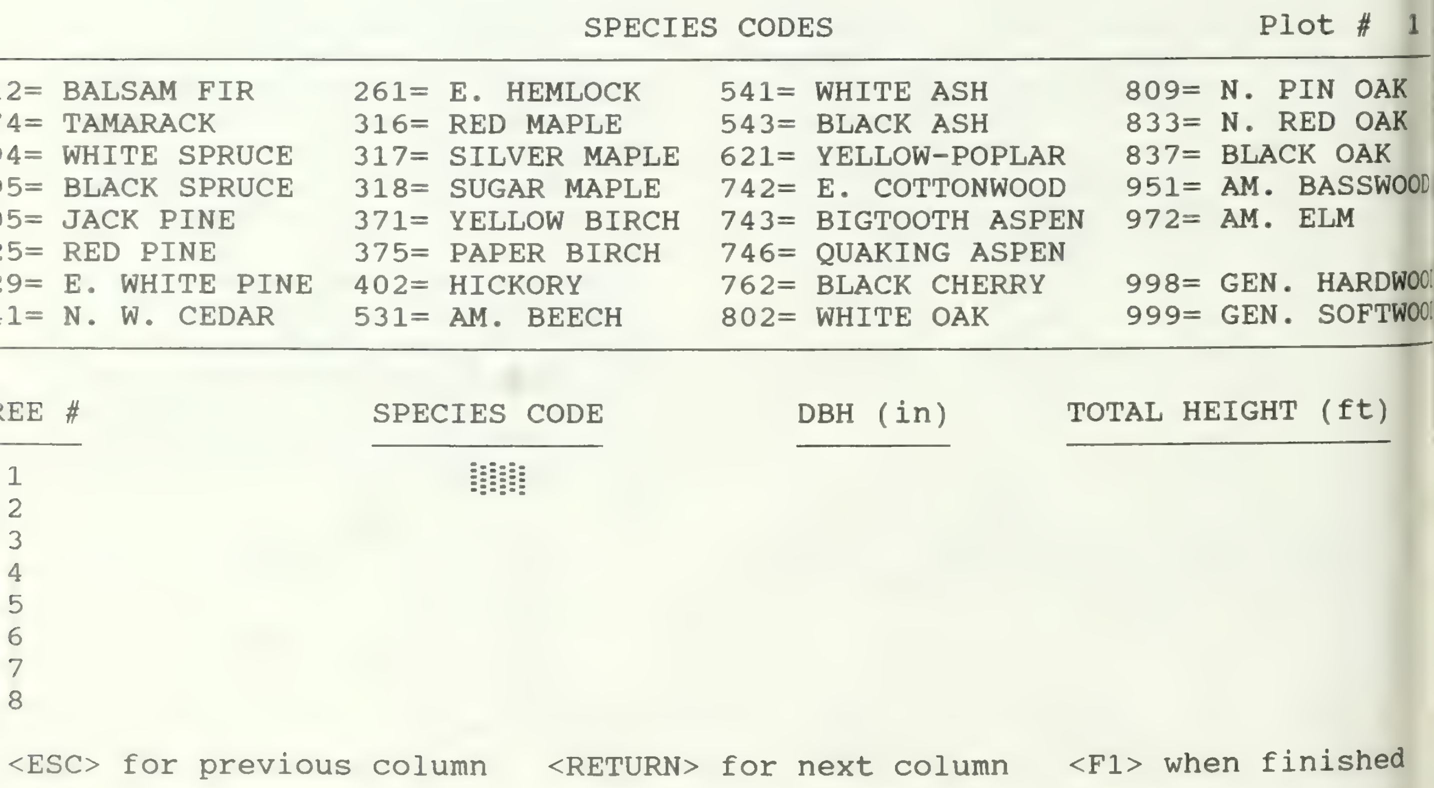
The Number of plots and Plotsize / BAF fields *must* be completed; the other entries are optional. When all the stand description information has been entered, the user presses the <F1> key; this writes the stand description data to disk (filename.DES) and transfers the user to the data entry screen.

Entering Individual Tree Data (Options 1, 2).—The Data Entry Screen displays the species codes and allows the user to enter the codes, heights, and diameters of up to 100 tree species/plot (fig. 1). The screen has a spreadsheet format: the user can move about the screen using the cursor arrows, <ESC>, and Return keys. Each line of the spreadsheet contains data for a single tree: the three digit species code, d.b.h. in inches, and total height in feet. All rows of data must be adjacent, i.e. there should be no blank lines within the block of data. When all data for a plot have been entered, the user presses the <F1> key; this writes the data from this plot to a disk file and begins data entry for the next plot. When the last plot has been entered, biomass values are calculated and the BIOMASS OUTPUT MENU is displayed.

Entering Average Plot Data (Options 3, 4).—Options 3 and 4 allow the user to enter average plot data. Data are entered as the *number* of trees of a given species found in a particular diameter/height class. These options simplify keyboard input of large amounts of data and allow input of data collected as stand averages. The Data Entry Screen for average data is identical to that for individual tree data, with an added column for the number of trees in a diameter-height class.

Using an Existing Data File - (Option 5).—Option 5 is used to select an existing input data file. The user is asked to specify the disk drive, and is presented with a list of the input data files on that drive. A file is selected by moving the cursor to the desired file and pressing the return (Enter) key. If needed, a stand description file may be created; otherwise the biomass values are calculated and the BIOMASS OUTPUT MENU is displayed.

Option 6 will save any open files to the designated disk and return the user to DOS.



```
                              SPECIES CODES                              Plot #  1
2= BALSAM FIR       261= E. HEMLOCK       541= WHITE ASH          809= N. PIN OAK
4= TAMARACK         316= RED MAPLE        543= BLACK ASH          833= N. RED OAK
4= WHITE SPRUCE     317= SILVER MAPLE     621= YELLOW-POPLAR      837= BLACK OAK
5= BLACK SPRUCE     318= SUGAR MAPLE      742= E. COTTONWOOD      951= AM. BASSWOOD
5= JACK PINE        371= YELLOW BIRCH     743= BIGTOOTH ASPEN     972= AM. ELM
5= RED PINE         375= PAPER BIRCH      746= QUAKING ASPEN
9= E. WHITE PINE    402= HICKORY          762= BLACK CHERRY       998= GEN. HARDWOO
1= N. W. CEDAR      531= AM. BEECH        802= WHITE OAK          999= GEN. SOFTWOO

EE #                 SPECIES CODE            DBH (in)       TOTAL HEIGHT (ft)

1
2
3
4
5
6
7
8

<ESC> for previous column   <RETURN> for next column   <F1> when finished
```

Figure 1.--*Data entry screen.*

Calculating Biomass

After the input data have been entered or read from an external file, control of the program passes to the BIOMASS CALCULATION subroutine. A running tally appears on the screen as these values are processed. When the calculations are complete, the results are written to a summary file (e.g. REDCEDAR.SUM) and the BIOMASS OUTPUT MENU is displayed.

Viewing Biomass Output - The BIOMASS OUTPUT MENU

The BIOMASS OUTPUT MENU presents reports of the output data in individual tree or expanded format. The user may choose English or metric units for the output and may send reports to a printer. The options of this menu are:

1) View Individual Tree Biomass
2) View Plot-level Expansion (lb/ac - kg/ha)
3) View Stand Description Data
4) Change Unit Type
5) Change Output Destination
6) Return to BIOMASS INPUT MENU
7) Exit BIOMASS

Option 1 allows the user to view the individual tree biomass values. Screen display of biomass values is presented plot by plot beginning with Plot 1. The plot number is displayed in the upper left corner of the screen. A maximum of 15 trees can be displayed on the screen at one time; remaining trees are displayed on the next screen. Trees are sorted by species code and diameter.

Option 2 of the OUTPUT MENU will expand biomass estimates from the individual tree level to an areal (lb/ac or kg/ha) basis. Selecting this option will also cause the areal estimates for species and plots to be written to disk files (file extensions **SP** and **PL**, respectively). The expansion factors are calculated from the basal area factor or fixed plot size specified in the stand description file.

Option 3 displays or prints the stand description data.

Option 4 allows the user to toggle between English and metric units for the individual tree summaries.

Option 5 allows the user to produce printed reports of the stand description data, individual tree, and plot expansion biomass values. The option toggles between screen-only and screen+printer outputs.

Option 6 returns the user to the MAIN INPUT MENU; this allows data from another stand to be be entered.

Option 7 closes all files and returns the user to the operating system.

Program Availability

To obtain copies of the BIOMASS program files contact:

Forestry Sciences Laboratory
North Central Forest Experiment Station
1831 HWY 169 E.
Grand Rapids, MN 55744

A list of registered users will be maintained and users will be notified as new biomass equations are added to the program. Comments and suggestions for this program are welcome and should be sent to the above address.

The computer program is available on request with the understanding that the U.S. Department of Agriculture cannot assure the accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

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BIOMASS is an interactive microcomputer program that uses allometric regression equations to calculate aboveground biomass of common tree species of the Lake States. The equations are species-specific and most use both diameter and height as independent variables. The program accommodates fixed area and variable radius sample designs and produces both individual tree and areal estimates of whole tree oven-dry weights.

KEY WORDS: Aboveground oven-dry weight, whole tree weight, allometric regression equations, dimension analysis.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

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Forest Service

North Central Forest Experiment Station

General Technical Report **NC-128**

Site Index Curves for Forest Tree Species in the Eastern United States

Willard H. Carmean, Jerold T. Hahn, and Rodney D. Jacobs

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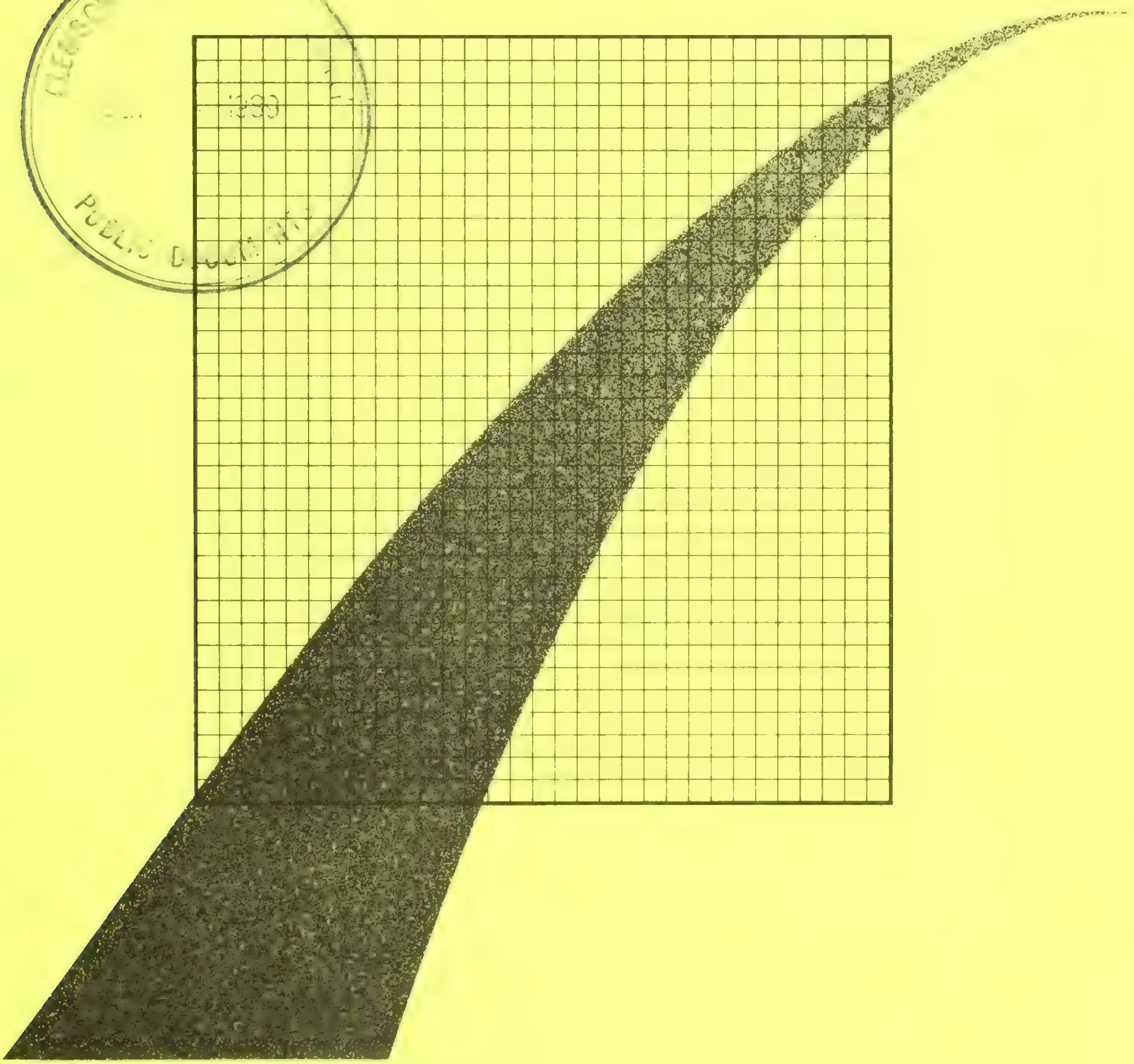

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Site Index Curves for Forest Tree Species in the Eastern United States

Willard H. Carmean, Jerold T. Hahn, and Rodney D. Jacobs

The goal of this paper is to inventory and summarize the site index curves available for forest tree species in the eastern United States. Hampf compiled a comprehensive list of site index curves in 1965, but many additional site index curves have been published in the more than two decades since this earlier summary. Accordingly, this paper is an updated summary that includes 127 site index curves presently considered to be useful for managing eastern hardwood and conifer forest species. Additional site index curves not included among the redrafted and formulated curves of our report are listed in Appendix I.

Forest site quality is an estimate of the capacity of forest land to grow trees, thus forest site quality corresponds to land capability for growing various agricultural crops. Productive forest land having good site quality usually should be managed most intensively, and less productive land having poor site quality usually should be managed less intensively. This same emphasis is followed in agriculture where intensive management is concentrated on the most productive cropland.

Many methods can be used to estimate forest site quality, but all methods have the common goal of classifying forest land's capability to grow trees (Carmean 1975). Directly estimating site index from forest trees is the most commonly used method for estimating site quality in North America. For most eastern forest species site index is defined as total height of dominant or total height of dominant and codominant trees at 50 years total age. However, age from breast height is sometimes used for species such as spruces, balsam fir, and red pine[1] that have slow and erratic height growth before reaching breast height. Younger index ages are sometimes used for plantations, short-lived species, or species managed on short rotations.

Tree height growth of dominant and codominant trees in pure, even-aged, fully stocked forest stands is closely related to volume growth. Accordingly, yield tables for pure natural stands and plantations list estimated yields at different ages for stands having different classes of site index. Growth and yield models also usually include site index as one of the major variables that is closely related to yield. Height growth is widely used as a measure of site quality because height in fully stocked stands is independent of stocking; height growth of dominant and codominant trees is reduced only at the extremes of overstocking or understocking (Carmean 1975, Lloyd and Jones 1983, Jones 1986, Lanner 1985.)

Accurate direct site index estimates depend upon two conditions: (1) availability of *suitable site trees* that are dependable indicators of site quality; and (2) availability of *suitable site index curves* that accurately portray tree height growth patterns for the area or for the soil and site conditions where site quality is estimated.

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[1] *See Appendix II for common and scientific names of tree species (Little 1979).*

Suitable site trees for site index estimates are free-growing, uninjured, dominant and codominant trees. Such trees occur in even-aged, fully stocked stands not disturbed by past cutting, severe fire, or heavy grazing. The best dominant and codominant trees in the stand should be carefully selected, and increment cores should be examined to see if annual rings in early years are wide and even. If early rings are narrow and suppressed, early height growth probably was suppressed and such trees should be rejected. Study the bole and look for forks or "dog legs". Trees with these defects probably have suffered from top breakage or die back and thus are not suitable as site trees.

Site trees should be selected from well-stocked even-aged stands having minimum age differences among dominant and codominant trees of no more than 10 years. Trees appreciably younger or older than the main stand may have different patterns of height growth and thus cause serious errors in site index estimation. For example, even-aged stands of upland oaks in the Missouri Ozarks may have occasional dominant and codominant trees appreciably younger or older than the main stand. McQuilkin (1975) found that appreciably younger trees had more rapid height growth, thus higher site index values, than trees in the main stand. Conversely, appreciably older trees had slower height growth, thus lower site index values, than trees in the main stand.

Site index measured from individual dominant and codominant trees may differ even on small plots that appear to have similar soil and microtopographic conditions. Thus, we are confronted with a sampling problem involving the number of site trees needed to obtain reliable site index estimates (Carmean 1975, Lloyd and Hafley 1977, Lloyd 1981). The number of site trees needed depends on many factors, including precision specified by the user, size of the area, and how much site quality differs within the defined stand. This sampling problem becomes more complex when we are dealing with large tracts of forest land that have variable soil, topographic, and site quality conditions. Such large land areas must be subdivided into smaller soil, topographic, or ecological units. Then site index sampling is done within each defined unit.

Suitable site index curves should be appropriate for the tree species, geographic region and the soil and/or topography of the stand. Even when suitable stands and site trees are available, large errors in site index estimation can occur when site index curves do not accurately express tree height growth patterns. In other words, initial or later height growth may be different from that expressed in existing site index curves. For many forest species, existing site index curves might be based on minimum data, mensurational methods using only total height and age values, and height growth models not suitable for expressing variable (polymorphic) tree height growth patterns.

Methods for collecting data and computing site index curves have evolved greatly since the first site index curves were published. The earliest curves were based on only a few plots and on total height and total age data from a few leading trees. These data were used to calculate an average guiding curve that would represent average height growth for a particular tree species. Graphical or proportional methods then were used to develop sets of anamorphic site index curves presumed to represent height growth throughout the range of the species. The unintentional assumption was that the pattern of tree height growth was similar for all levels of site quality, and for all climates, soils, and topographic conditions found throughout the range of the tree species (Carmean 1968).

The next development was the construction of proportional anamorphic site index curves that often accompanied normal yield tables for major forest types. Total height and age measurements from yield plots were used to calculate an average guiding curve; then harmonizing methods were used to develop a set of proportional curves for a range of good and poor sites. Some of the old curves included with yield studies were based on graphical methods, some on least squares regression, and some on harmonizing methods. Almost all of these methods resulted in a family of anamorphic site index curves that had the same shape regardless of site index level. They were proportional and differed only in rate of height growth for different levels of site quality.

A key point is that these older curves were not based on actual measurements of tree height growth but instead on total height and age measured from the yield study plots. These older anamorphic curves were often erroneous because plots representing good and poor sites might not be distributed through all age classes. For example, older-aged stands might be represented by mostly poor-site plots, and younger-aged stands might be represented by mostly good-site plots. The result would be a downwarping of the average guide curve for older ages and an upwarping of the guide curve for younger ages.

Unfortunately, these general anamorphic curves were often applied in far distant areas where climate, soils, topography, site quality, and stand conditions differed greatly from the original study area. We now know that tree height growth is often polymorphic, and that many species covering wide ranges have different height growth patterns for areas differing greatly in climate, soil, topography, and site quality (Carmean 1968, 1975).

Stem analysis (or internode measurements) is now the most widely used method for collecting data, and nonlinear regression models are subsequently used for developing site index curves that express polymorphic tree height growth patterns. More precise site index curves based on stem analyses and nonlinear regression models are now replacing the older generalized curves that have been shown to be inaccurate. Additional discussion of methods for constructing site index curves is given by Burkhart *et al.* (1981), Clutter *et al.* (1983), Borders *et al.* (1984), and Biging (1985).

Inventory of Site Index Curves

The forestry literature includes a vast number of site index curves for the many eastern forest species; thus, the 127 site index curves in this summary represent only a small portion of the many curves found in our literature search to compile this summary. Many curves are not included because they are revisions or adaptations of earlier site index curves. For example, a large number of site index curves have been published for red pine (Carmean 1982). At first glance we might assume that this impressive wealth of curves is adequate for estimating site quality for red pine. However, such an assumption would be inaccurate because closer inspection reveals that many curves are merely a republishing or a revision of the original Brown and Gevorkiantz (1934) red pine data. Later site curves for red pine involved formulations for the earlier anamorphic curves (Lundgren and Dolid 1970, Hahn and Carmean 1982) or are metric expressions for these earlier curves (Laidly 1979).

Formulations for many eastern species have been published by Payandeh (1974a, 1974b), Farrar (1973, 1975, 1985), Monserud and Ek (1976), Guldin and Farrar (1983), and Scott and Voorhis (1986). Most of these formulations are based on older site index curves, thus the formulated curves may have the same data deficiency and computation problems associated with the original anamorphic curves. Formulations aid in making more rapid and consistent computations but cannot correct for data and computation deficiencies inherent in the original site index curves.

Many older site index curves were not included because they were based on minimum data from questionable stand or tree conditions. Many of the older curves contained no account of kinds of stands or trees measured, ranges of site index or age observed, or the graphical or computational methods used to develop the site index curves. Many of the older curves listed in Appendix I have been replaced by newer curves based on more data, stem analyses methods, and mathematical models capable of expressing polymorphic height growth patterns. These older curves are listed for historical purposes and for those interested in more complete site index curve coverage for certain tree species (Appendix I).

We made an effort to include curves for all forest species; thus, we included curves for certain minor species that are represented only by older and questionable site index curves. Also major forest species such as oaks and pines have wide ranges representing a wide range of climate, soil, topography, and site quality. A large number of curves are given for these wide-ranging species so that forest managers can select the set of curves most suited to local forest conditions. Several Canadian site index curves are included because they are considered applicable to the northern United States. Finally, species that are widely planted are represented by many site index curves based on data collected in older plantations located in different climatic, soil, and topographic regions.

Formulations

Many of the curves included in this report have already been formulated; thus, we used equations from these publications to generate values for our formulations. However, because some older curves were never formulated, we used values directly from the original curves as the basis for the formulations we give for these curves. Thus our formulations were accomplished using (1) height-age values generated either by the original equations or by more recent formulations, or (2) values from the original site index curves. All formulations listed for each of the 127 site index curves in this report are based on a single standard model. The model used for our formulations is a nonlinear height growth model capable of expressing polymorphic tree height growth patterns. This model is an expanded form of the Chapman-Richards nonlinear function developed by Ek (1971), Payandeh (1974a, 1974b), and Monserud and Ek (1976):

$$H = BH + b_1 S^{b_2} \left(1 - e^{b_3 A}\right)^{b_4 S^{b_5}} \qquad (1)$$

where H = height, BH = 0 when A is total age and 4.5 when A is d.b.h. age, S = site index, A = age, e = base of the natural logarithms, and the b_i are regression parameters.

Most site index curves are a family of height growth curves with site index defined as tree height at a specified index age. These curves can be used to graphically estimate site index merely by relating measured tree height and age values to the curves and then interpolating between the curves. However, this graphical procedure is slow and inefficient when a large number of height and age values are available for estimating site index. Also this graphical procedure is subject to some personal bias and judgment when interpolating between the plotted site index curves. More rapid, more efficient, and less subjective site index estimates can be attained using a formulation for directly computing site index given tree height and age.

Site index cannot be computed using model (1), but an analogue suggested by Payandeh (1974b) provides a form for directly computing site index. Curves computed with this site index prediction model may not pass exactly through tree height specified at index age, but this problem can be solved by using a weighted regression with a weight of (index age - 2 abs[2] (age - index age)). This procedure ensures close agreement at index age with a somewhat poorer, yet acceptable, fit at the extremes of age and site index. The maximum difference from the data used is shown in the figure caption. Following is the model used to estimate site index, given age and height, for each of the curves included in this report:

$$S=BH+c_1H^{c_2}\left(1-e^{c_3A}\right)^{c_4H^{c_5}} \qquad (2)$$

where H, BH, A, S, and e are as in equation (1) and c_i are regression parameters.

Both models were fit using the NONLINEAR subprogram of the Statistical Package for the Social Sciences (SPSS) (Nie *et al.* 1975) with weights as specified above.

Preparing the Site Index Curves

The original site index curves usually consisted of curves for a series of 10-foot site index classes. These general curves were often ungridded, which made it difficult to interpolate between lines. Also, some of the very old curves only had a few individual height growth curves rather than a family of proportional site index curves. Our revisions for each of the 127 site index curves in this report include curves for 5-foot site index classes and a gridded background to assist in interpolating between site index lines.

The revised curves were plotted using values generated from the height formulations listed in the figure caption for each curve. These formulated and redrafted curves closely follow the range of site index and age included in the original curves. Extrapolations indicated in the original curves also are indicated by dashed lines in the redrafted curves. The 127 curves are grouped first by hardwood and conifer species and then alphabetically by scientific name.

Using the Site Index Curves

Each of the 127 site index curves can be directly used to graphically estimate site index when appropriate height and age values are available from suitable dominant, or dominant and codominant trees. To do this, relate height and age values to the site curves and then interpolate between curves.

Site index also can be estimated using a computer or programmable calculator together with the formulations for the site index equations listed in the caption for each figure. First, equation coefficients for each figure and a simple program for solving the equation are entered and stored in the computer. Then site index is estimated by manually entering the figure code together with measured height and age values. Computing site index using these formulations is rapid and efficient when a large number of height and age values are available for estimating site index. Computing site index also avoids errors and bias that might occur when interpolating between curves.

These revised, redrafted, and formulated site curves still contain the limitations that may be associated with the original site index curves. The original curves may be based on data representing a limited range of soils, topography, and site quality, and data may have been collected from stands and site trees not entirely suitable for constructing site index curves. Also the original curves may have been developed by graphical or anamorphic methods and may have used equation models not capable of expressing polymorphic height growth. These original data or computation defects cannot be corrected by revisions or formulations. Accordingly, the caption for each of the 127 site index curves briefly states the study area, number of plots and trees measured, kind of data collected, and computation methods used to develop the original site curves. Such information will help the user decide which set of curves is most appropriate for use in a particular area and also will indicate the reliability of the site index curves presently available for use in that area.

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[2] *Absolute value of...*

What can be done when a particular area or tree species lacks published site index curves, or when all that exists are a few, older anamorphic curves of questionable accuracy? One alternative is to restrict site index estimates to stands close to index age. For example, if the site trees are exactly 50 years of age (index age), no error occurs because their present height is site index. Possibly, site index estimation could be restricted to stands ranging from 35 to 65 years. Thus, the maximum extrapolation would be 15 years forward or back to index age, and errors due to faulty site index curves would be minimal. Using stands at or close to index age will minimize errors in estimating site index—that is, tree height at index age. However, we should bear in mind that site index is tree height at only one point in time (index age). We also should be concerned about patterns of tree height and volume growth before and after index age. Thus, we need site index curves that accurately portray height growth throughout the life of the stand. This view uses a site index value only as a convenient label for an accurately defined height-age curve that passes through a specified height at index age.

A second alternative is to fell a few dominant and codominant trees, make a stem analysis, and construct individual tree height-age curves (Erdmann and Peterson 1982). These tree height-age curves then are used to observe (1) how tall trees were at the specified site index age and (2) early and later tree height growth patterns.

A third and more desirable alternative for species and areas lacking suitable site index curves is to encourage research needed for developing more precise site index curves. These more precise curves should be based upon stem analysis and equation models capable of expressing polymorphic height growth patterns.

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Appendix I

Additional Site Index Curves

References are given below for additional site index curves not included in the formulated and redrafted curves of this report. These additional references may be of historical interest, or they may be of value to those interested in more complete coverage for certain forest species.

Inventory of Site Index Curves

Species	Area	Reference
Hardwoods:		
Sugar maple	Vermont	Hawes and Chandler (1914)
Sugar maple, white ash	Vermont	Farrington and Howard (1958)
Sugar maple	New York	Farnsworth and Leaf (1963)
Sugar maple	N. lower Mich.	Shetron (1972)
Northern hardwood spp.	Lake States and NE States	Frothingham (1915b)
N. hardwood spp.	Lake States	Monserud and Ek (1976)
N. hardwood spp., paper birch, aspen	Ontario	Plonski (1960)
Red maple	NW Conn., W. Mass.	Foster (1959)
American beech	Northeast US.	Hampf (1965)
Sweetgum	C. Mississippi	Clatterbuck (1987)
Yellow-poplar	SE Ohio, Western Va.	McCarthy (1933)
Quaking and bigtooth aspens	Michigan	Graham *et al.* (1963)
Quaking aspen	N. Minnesota	Schlaegel (1971)
Black cherry	New York	Hampf (1965)
Black cherry	NW Pennsylvania	Ward *et al.* (1965)
Upland oaks	NW West. Va.	Lamson (1980)
Upland oaks	Central States	Hilt and Dale (1982)
Cherrybark oak	C. Missisippi	Clatterbuck (1987)
Conifers:		
Spruces and balsam fir	N. Michigan	Bowman (1944)
Spruces and balsam fir	Maine	Mount and Gore (1952)
Spruces and balsam fir	Northeast U.S.	Meyer (1929)
Black spruce	N. Minnesota	Averell and McGrew (1929)
Black spruce, jack pine, red pine, white pine, aspen, white birch, tolerent hwds	Ontario	Plonski (1974)
Black spruce	E. Canada	Heger and Lowry (1970)
Red spruce	N. Maine	McLintock and Bickford (1957)
Norway spruce	Central New York	Jokela *et al.* (1988)
Jack pine	Lake States	Sterrett (1920)
Slash, longleaf, loblolly, shortleaf and Virginia pines	Southeast U.S.	Cruikshank (1954)
Slash pine	Georgia	Bennett (1960)
Slash pine plantations	West Gulf	Bailey *et al.* (1973)
Slash pine plantations	Florida	Hebb and Burnes (1973)
Slash pine plantations	Georgia and N. Florida Coastal Plain	Newberry and Pienaar (1978)
Loblolly pine	Virginia, N. and S. Carolina	MacKinney (1936)
Loblolly and shortleaf pines	N. Carolina Piedmont	Coile and Schumacher (1953)
Loblolly pine stands & plantations	Va., N.C., Md., Del.	Devan and Burkhart (1982)
Loblolly pine plantation	N.C. to SW Ark.	Golden *et al.* (1981)
Loblolly pine plantations	NE Texas	Lenhart and Fields (1970)
Loblolly and slash pine plantations	E Texas	Lenhart, Hunt, and Blackard (1986)
Pitch pine	Pennsylvania	Illick and Aughanbaugh (1930)
Red pine	Central New England	Reed (1926)
Red pine	Northeast and Lake States	Spurr (1956)
Red pine	N. Minnesota	Alban (1976)
Red pine plantations	Connecticut	Bull (1931)
Red pine plantations	Pennsylvania	Kinsley and Bartoo (1967)
Red and white pine plantations	SE Ohio, S. Indiana	Gaiser and Merz (1953)
Red pine plantations	Michigan	Van Eck and Whiteside (1963)
Red pine plantations	S. Ontario	Beckwith *et al.* (1983)
White pine	Northeast U.S.	Frothingham (1914)
White pine	S. Appalachians	Barrett (1934)
White pine	S. Appalachians	Doolittle and Vimmerstedt (1960)
White pine	New Hampshire	Husch (1954)
White pine	Northeast U.S.	Leak *et al.* (1970)
White pine	Maine, Mass., New Hampshire	Barrett and Goldsmith (1973)
Northern white-cedar	Lake States	Gevorkiantz and Duerr (1939)

Appendix II

Common and Scientific Names of Tree Species (Little 1979)

Common name	Scientific name
Balsam fir	*Abies balsamea* (L.) Mill.
Red maple	*Acer rubrum* L.
Silver maple	*Acer saccharinum* L.
Sugar maple	*Acer saccharum* Marsh.
Yellow birch	*Betula alleghaniensis* Britton
Paper birch	*Betula papyrifera* Marsh.
Hickories	*Carya* spp. Nutt

Atlantic white-cedar	*Chamaecyparis thyoides* (L.) B.S.P.
American beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
Black ash	*Fraxinus nigra* March.
Green ash	*Fraxinus pennsylvanica* Marsh.
Black walnut	*Juglans nigra* L.
Eastern redcedar	*Juniperus virginiana* L.
European larch	*Larix decidua* Mill.
Tamarack	*Larix laricina* (Du Roi) K. Koch
Japanese larch	*Larix leptolepis* (Sieb and Zucc.) Gard.
Sweetgum	*Liquidambar styraciflua* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Water tupelo	*Nyssa aquatica* L.
Swamp tupelo	*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.
Norway spruce	*Picea abies* (L.) Karst.
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Red spruce	*Picea rubens* Sarg.
Jack pine	*Pinus banksiana* Lamb.
Sand pine	*Pinus clausa* (Chapm.) Vasey
Shortleaf pine	*Pinus echinata* Mill.
Slash pine	*Pinus elliottii* Engelm.
Longleaf pine	*Pinus palustris* Mill.
Red pine	*Pinus resinosa* Ait.
Pitch pine	*Pinus rigida* Mill.
Pond pine	*Pinus serotina* Michx.
Eastern white pine	*Pinus strobus* L.
Scotch pine	*Pinus sylvestris* L.
Loblolly pine	*Pinus taeda* L.
Virginia pine	*Pinus virginiana* Mill.
Cottonwood	*Populus deltoides* Bartr.
Bigtooth aspen	*Populus grandidentata* Michx.
Quaking aspen	*Populus tremuloides* Michx.
Black cherry	*Prunus serotina* Ehrh.
White oak	*Quercus alba* L.
Scarlet oak	*Quercus coccinea* Muenchh.
Southern red oak	*Quercus falcata* Michx.
Cherrybark oak	*Quercus falcata* var. *pagodifolia* Ell.
Water oak	*Quercus nigra* L.
Nuttall oak	*Quercus nutallii* Palmer
Chestnut oak	*Quercus prinus* L.
Northern red oak	*Quercus rubra* L.
Black oak	*Quercus velutina* Lam.
Black locust	*Robinia pseudoacacia* L.
Northern white-cedar	*Thuja occidentalis* L.
American basswood	*Tilia americana* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
American elm	*Ulmus americana* L.

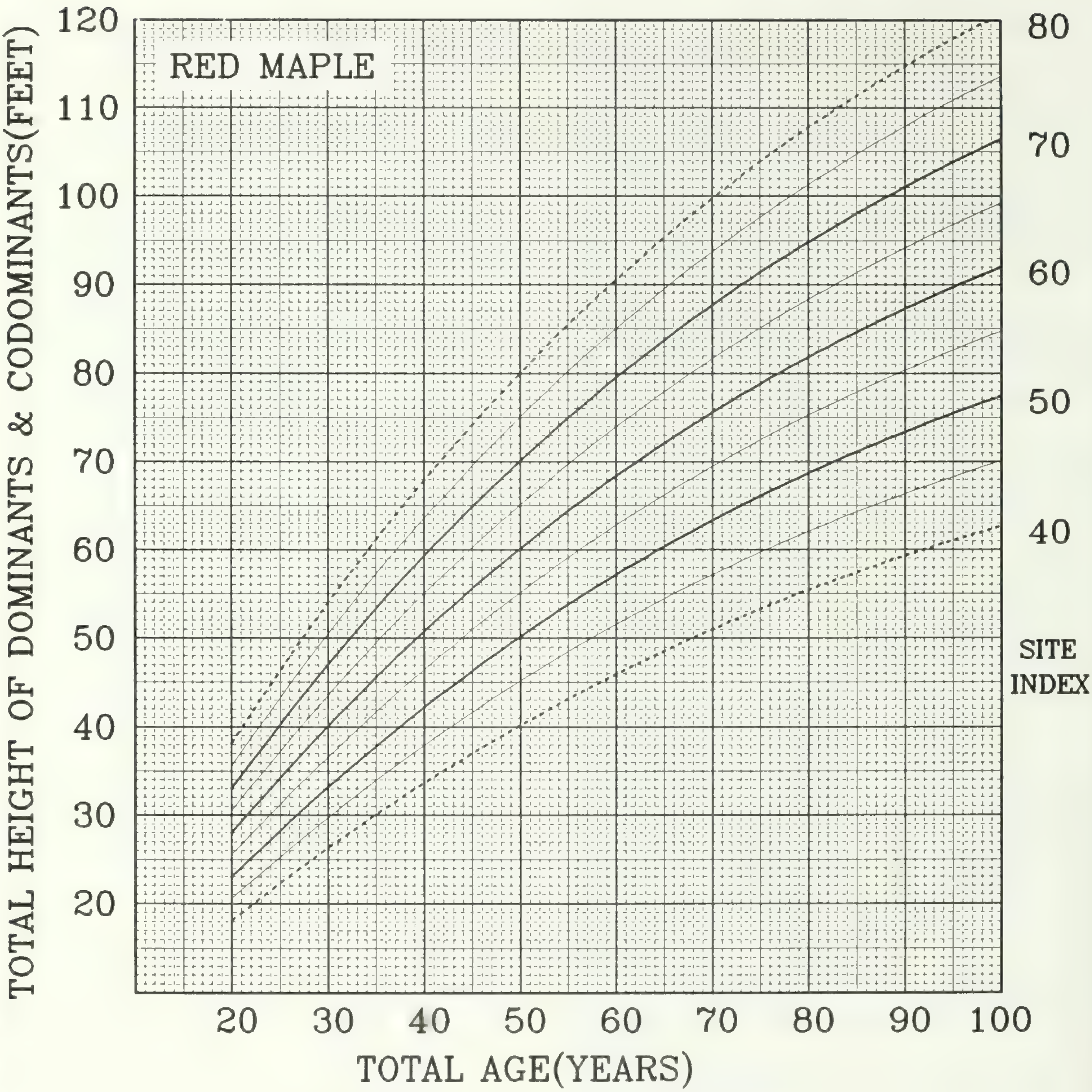

Figure 1.—Red maple (Carmean 1978)
Northern Wisconsin and Upper Michigan
114 plots having 438 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.9435	0.9132	-0.0141	1.6580	-0.1095	0.99	0.49	2.0
SI	0.3263	1.0634	-0.0106	-1.2573	-0.0646	0.99	0.51	2.2

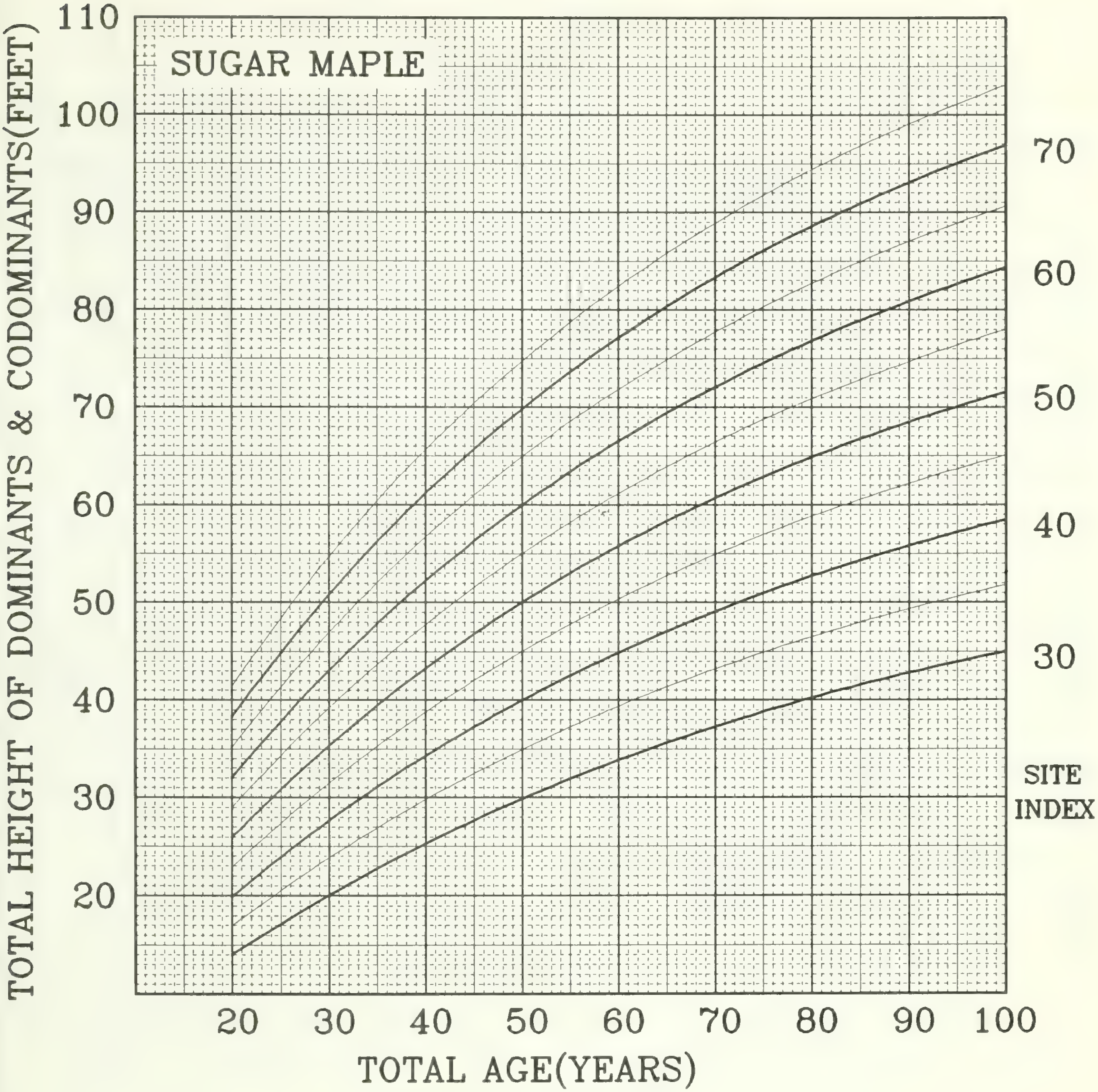

Figure 2.—Sugar maple (Curtis and Post 1962, Solomon 1968)
Vermont Green Mountains
67 plots having 136 dominant and codominant trees
Stem analysis, logarithm equation, anamorphic, original curves redrafted from d.b.h. age to total age and from SI age 75 to SI age of 50
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	3.3721	0.8407	-0.0150	2.6208	-0.2661	0.99	0.88	0.3
SI	0.1771	1.2075	-0.0066	-1.7003	-0.2189	0.99	0.98	1.9

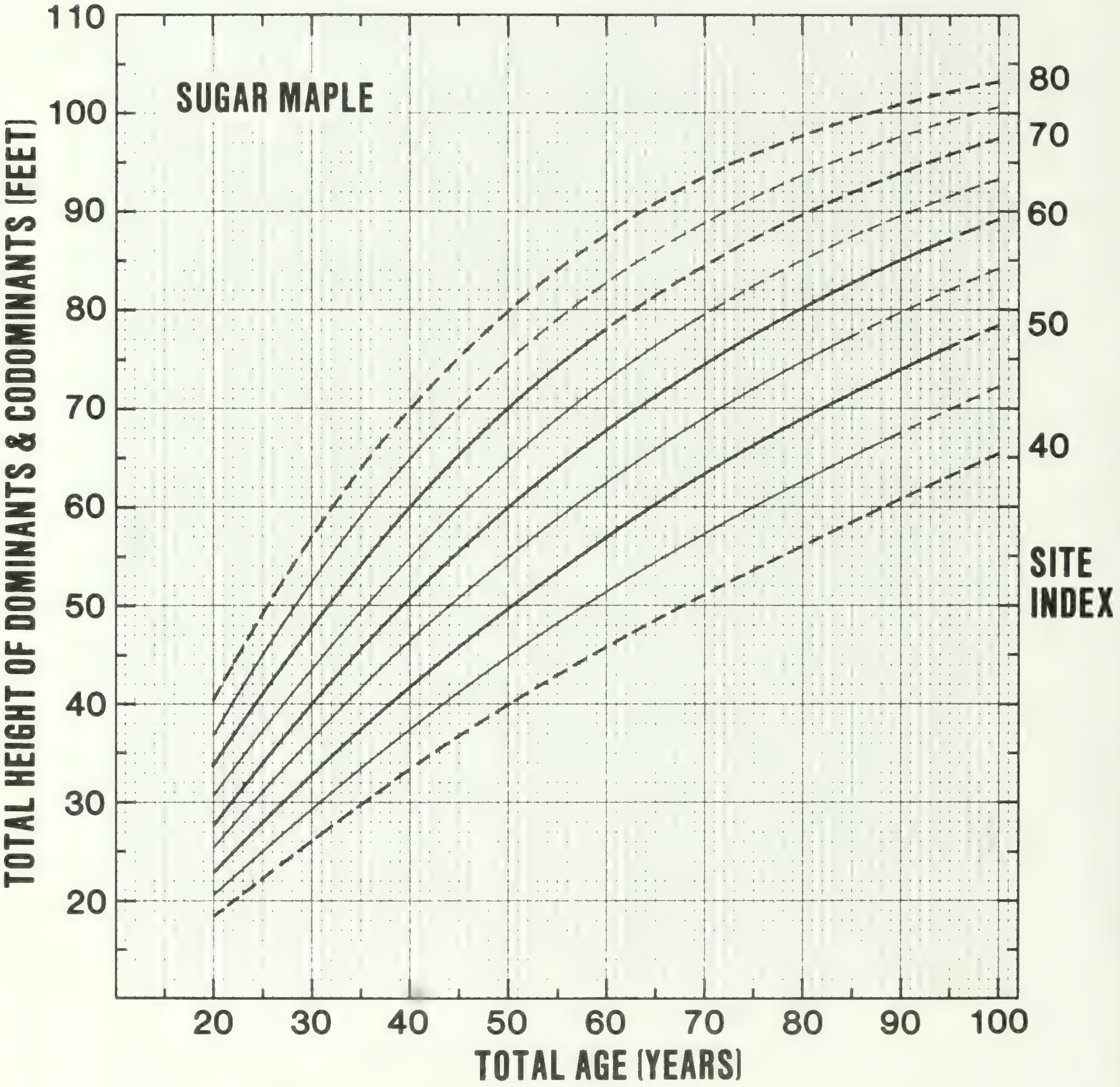

Figure 3.—Sugar maple (Carmean 1978)
Northern Wisconsin and Upper Michigan
177 plots having 721 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.1308	0.6904	-0.0195	10.1563	-0.5330	0.99	1.26	5.3
SI	0.1984	1.2089	-0.0110	-2.4917	-0.2542	0.98	1.90	6.7

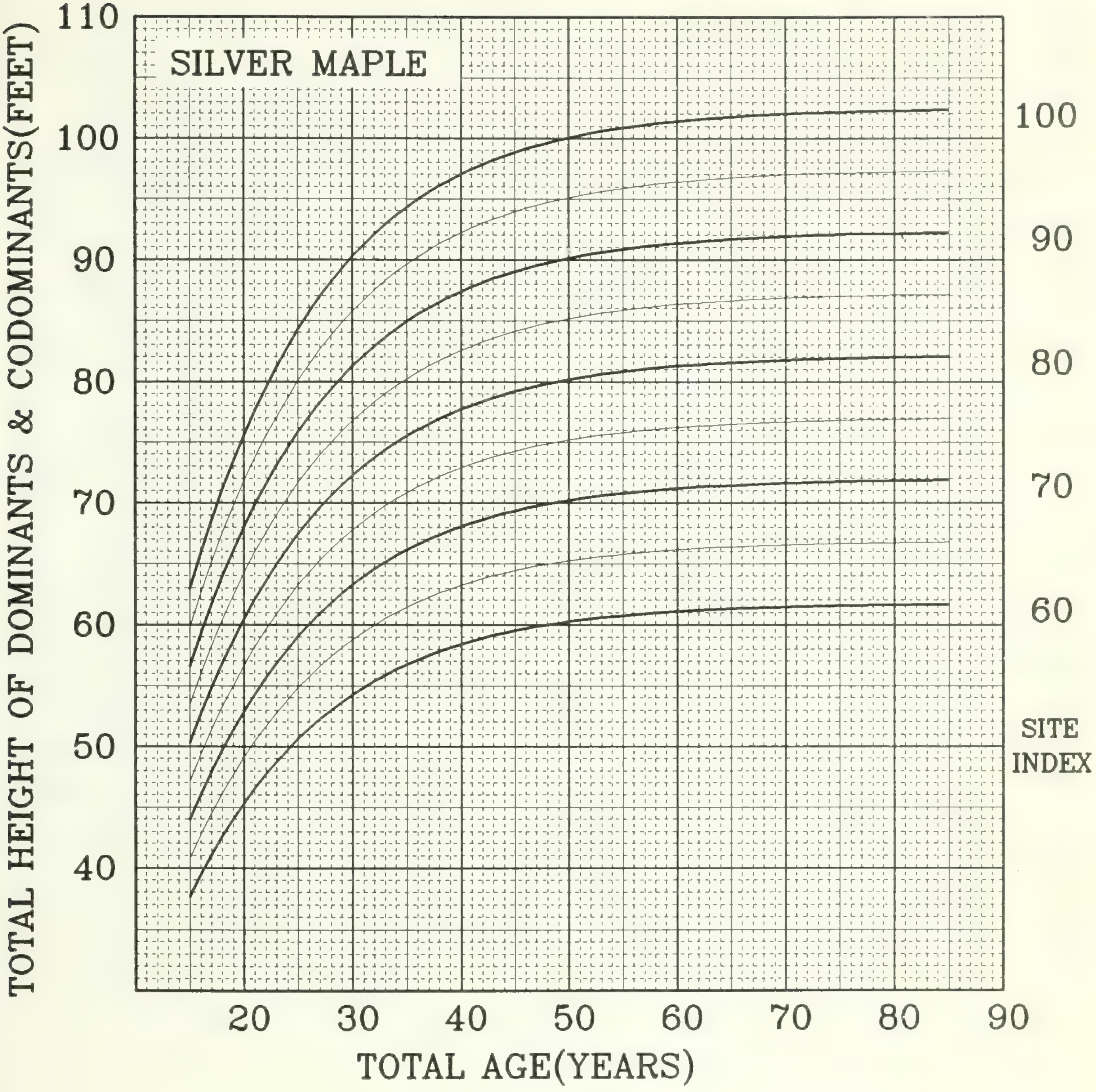

Figure 4.—Silver maple (Brendemuehl, McComb, and Thomson 1961b)
Southeastern Iowa
50 plots, number of dominant and codominant trees not given
Total height and age, anamorphic, equation not given
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0645	0.9918	-0.0812	1.5754	-0.0272	0.99	1.00	4.2
SI	0.8972	1.0183	-0.0769	-4.8154	-0.3162	0.99	0.95	6.0

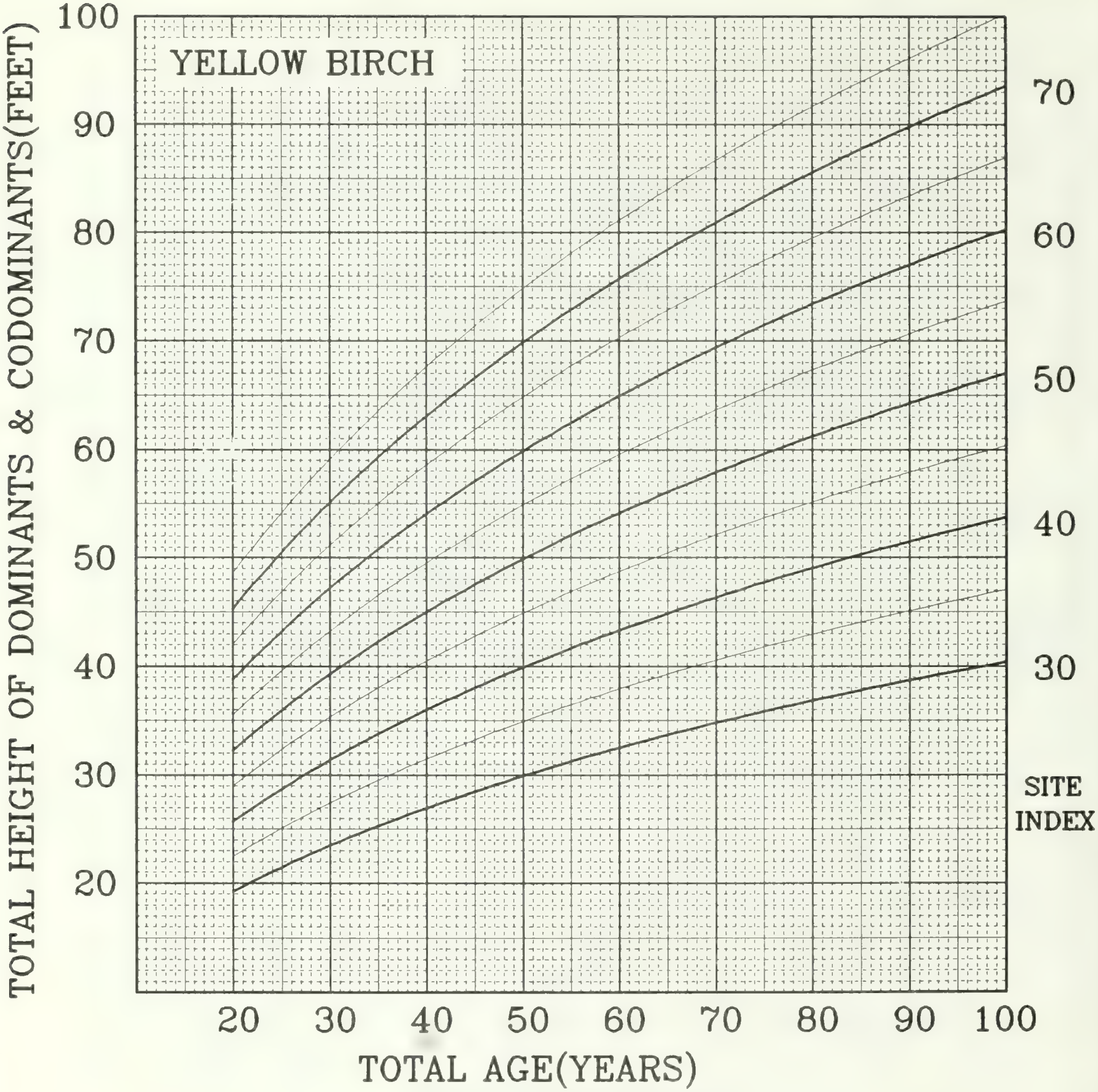

Figure 5.—Yellow birch (Curtis and Post 1962, Solomon 1968)
Vermont Green Mountains
38 plots having 68 dominant and codominant trees
Stem analysis, logarithm equation, anamorphic, original curves redrafted from d.b.h. age to total age and from SI age of 75 to SI age of 50
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.2835	0.9794	-0.0054	0.5819	-0.0281	0.99	0.78	1.0
SI	0.5889	0.9922	-0.0096	-0.5473	0.0146	0.97	0.47	0.3

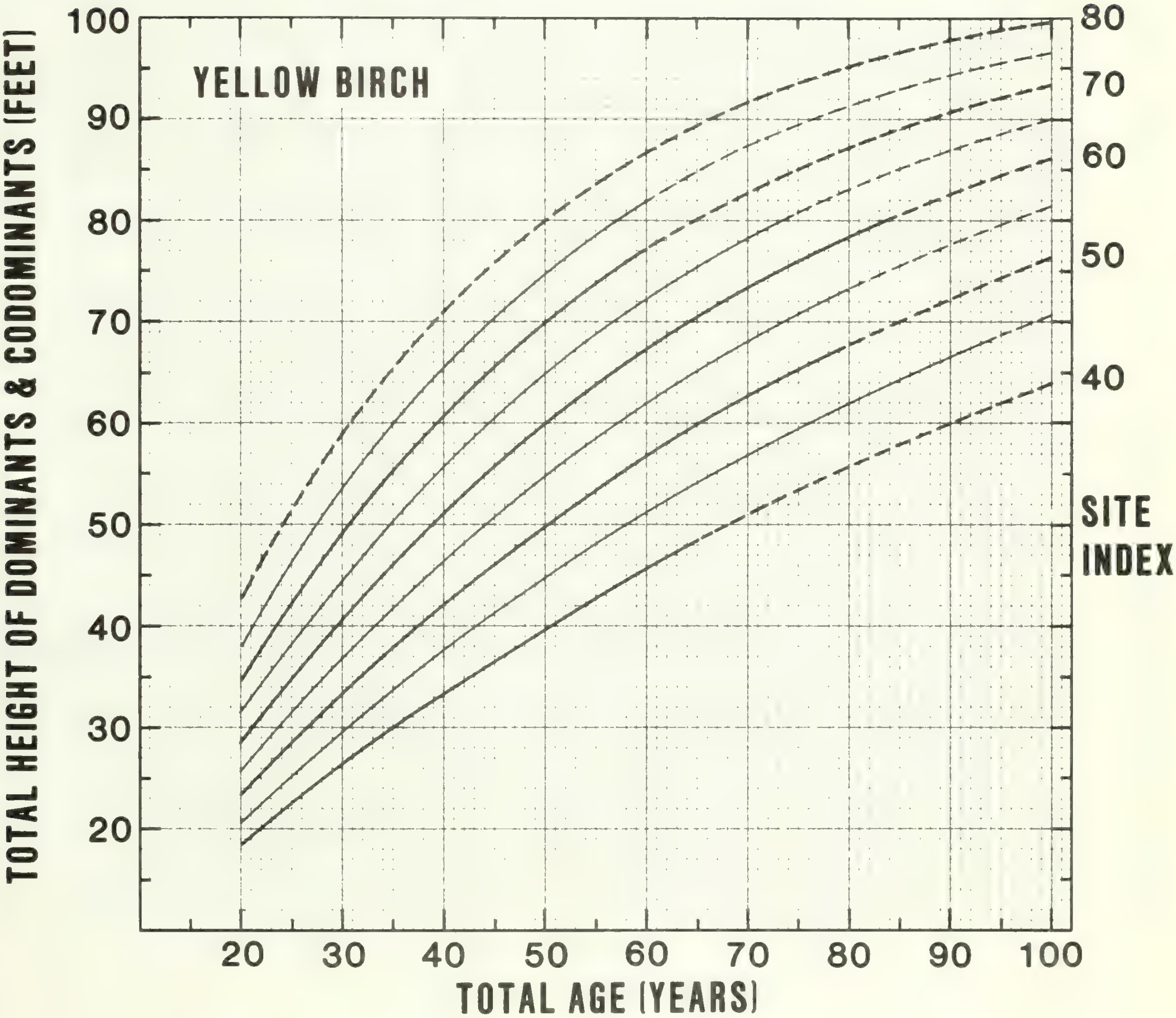

Figure 6.—Yellow birch (Carmean 1978)
Northern Wisconsin and Upper Michigan
119 plots having 459 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.0522	0.6768	-0.0217	15.4232	-0.6354	0.99	1.29	5.0
SI	0.1817	1.2430	-0.0110	-3.0184	-0.3180	0.98	2.05	7.7

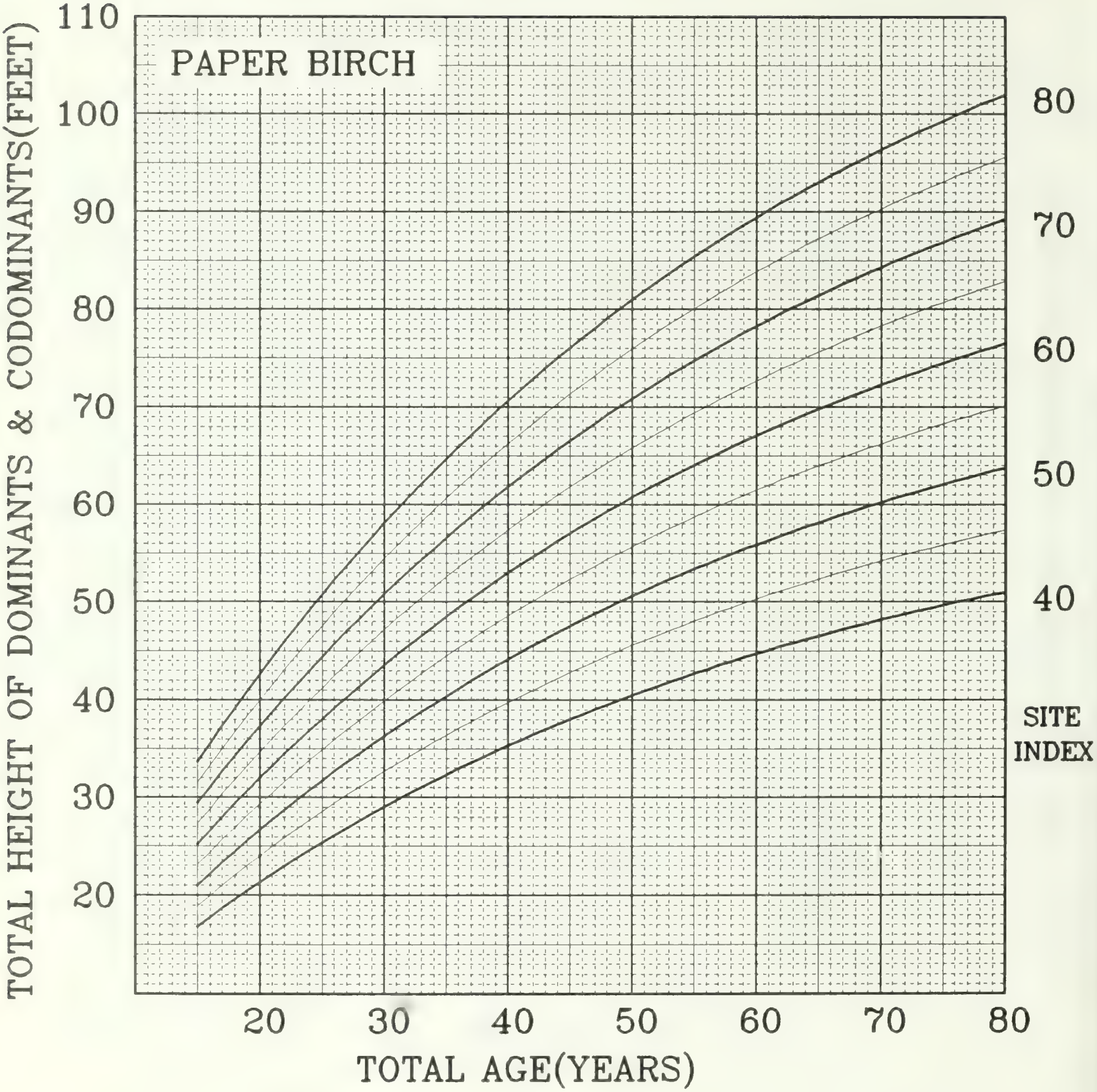

Figure 7.—Paper birch (Cooley 1958, 1962)
Northern Wisconsin (104 plots); Upper Michigan (4 plots)
108 plots, number of dominant and codominant trees not given
Total height and age, anamorphic, equation not given
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5980	1.0000	-0.0198	0.9824	0.0000	0.99	0.32	0.6
SI	0.6258	1.0000	-0.0198	-0.9824	0.0000	0.99	0.32	0.6

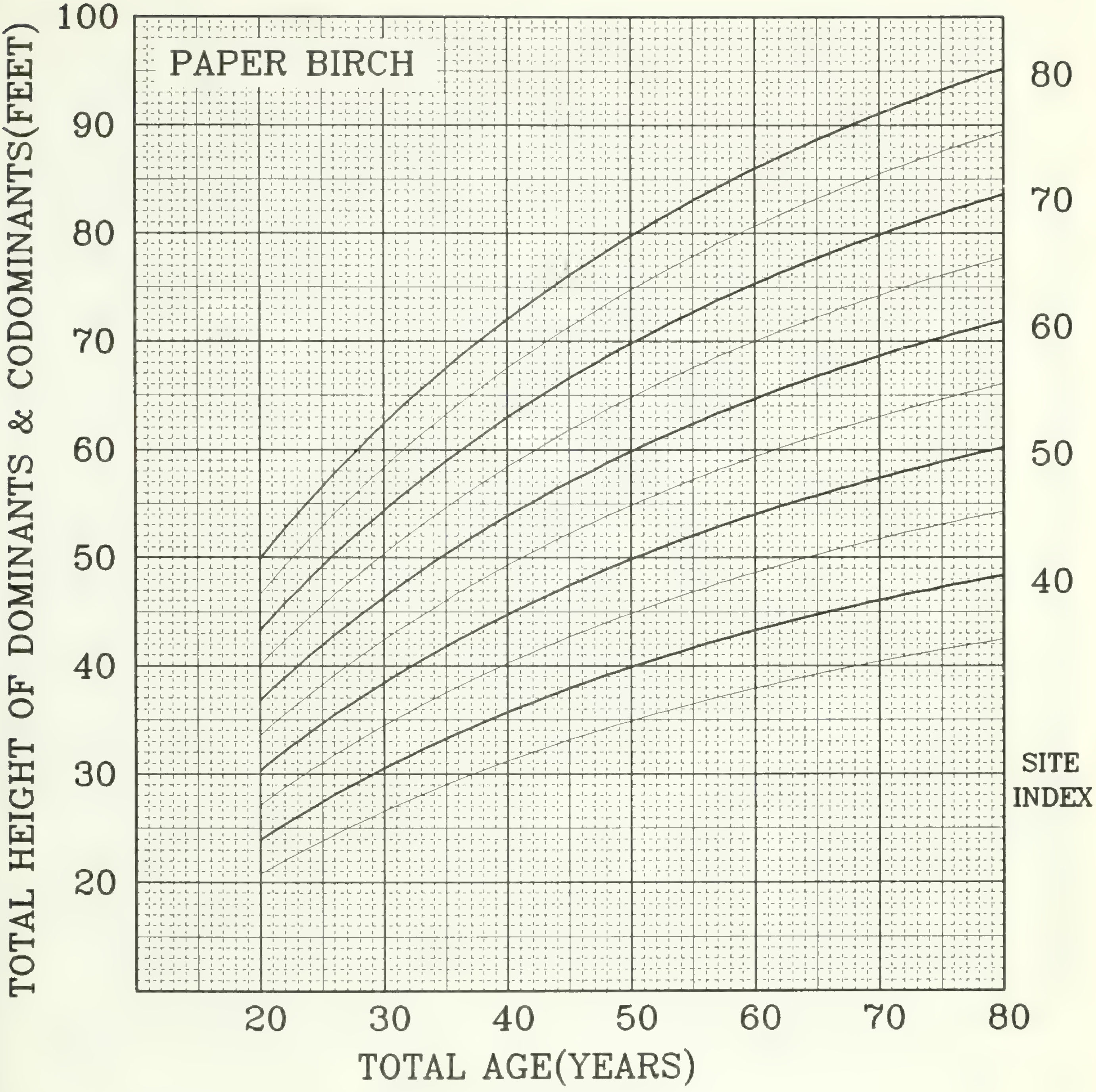

Figure 8.—Paper birch (Curtis and Post 1962, Solomon 1968)
Vermont Green Mountains
32 plots having 56 dominant and codominant trees
Stem analysis, logarithm equation, anamorphic, original curves redrafted from d.b.h. age to total age and from SI age 75 to SI age of 50
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.7902	0.9522	-0.0173	1.1668	-0.1206	0.98	0.91	1.1
SI	0.5542	1.0540	-0.0184	-1.3053	-0.1435	0.96	0.49	0.6

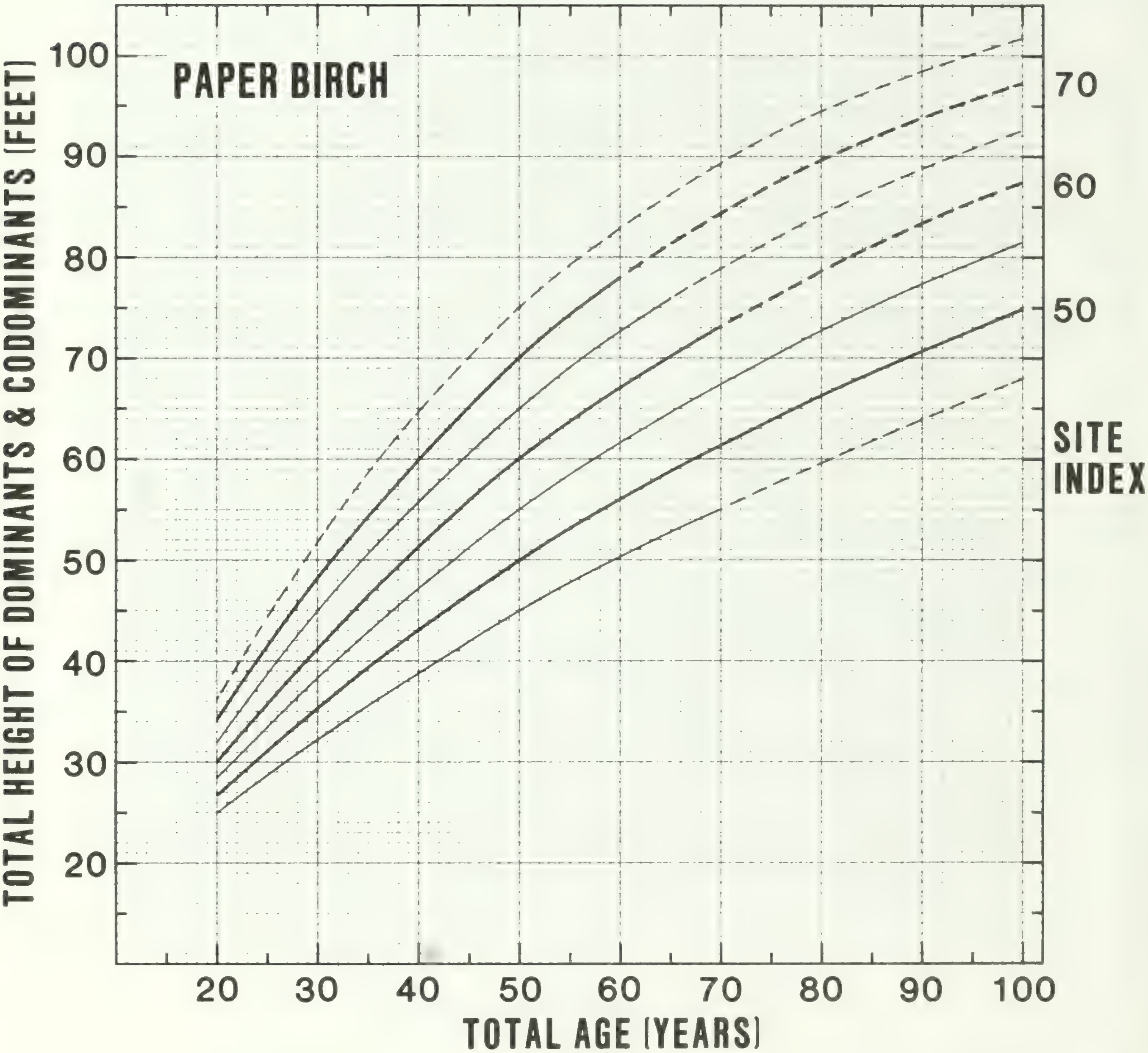

Figure 9.—Paper birch (Carmean 1978)
Northern Wisconsin and Upper Michigan
30 plots having 93 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.4321	0.9207	-0.0168	1.5247	-0.1042	0.99	1.06	4.2
SI	0.5119	1.0229	-0.0167	-1.0284	-0.0049	0.98	1.07	4.3

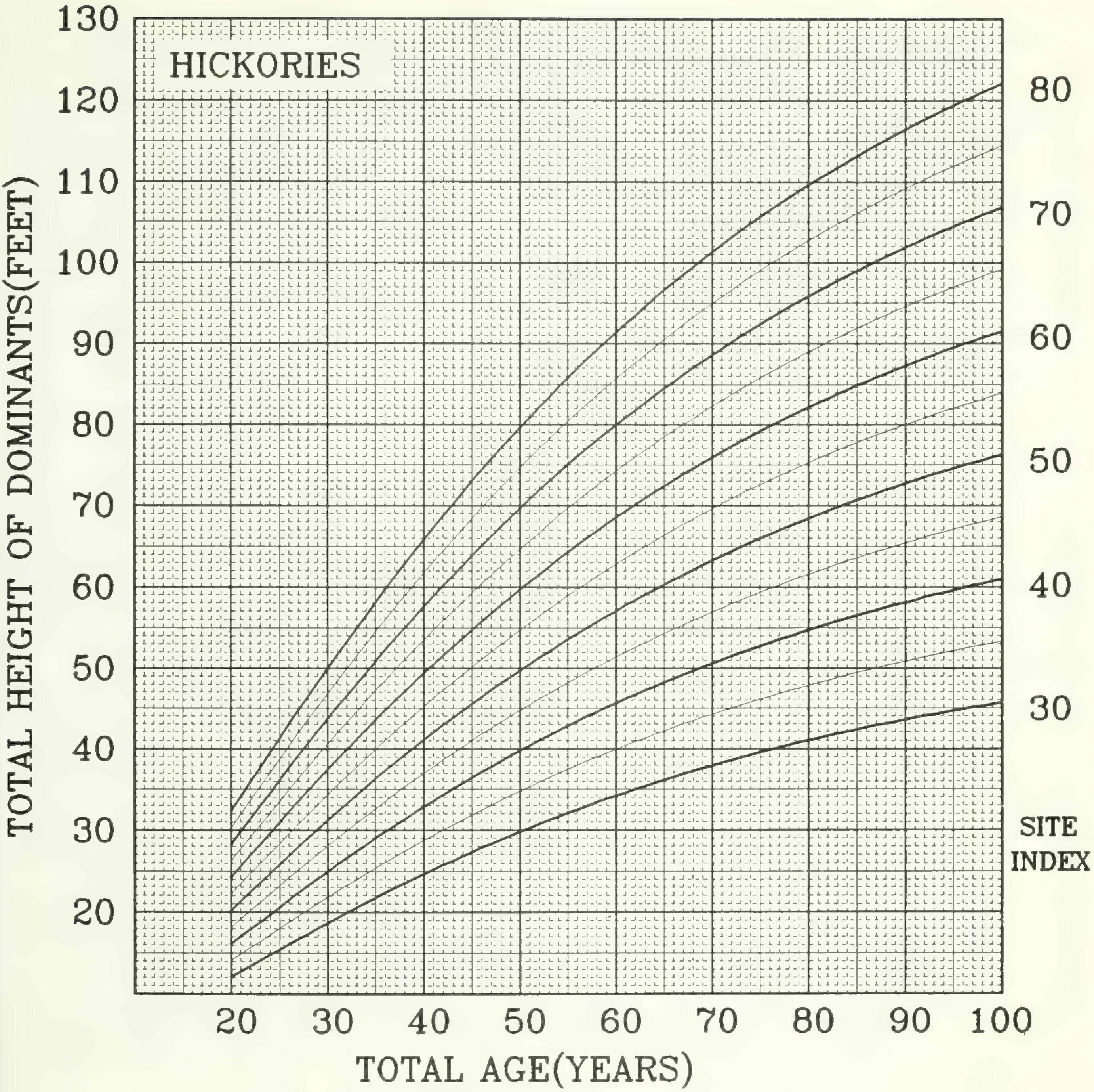

Figure 10.—Hickories (Boisen and Newlin 1910, Hampf 1965)
Central States, Cumberland Mountains of Kentucky
30 plots, number of dominant trees not given
Total height and age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30	40	50	60	70	80
Years:	10	8	7	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.99	0.60	2.1
SI	0.5243	1.0126	-0.0216	-1.5897	-0.0239	0.99	0.62	2.3

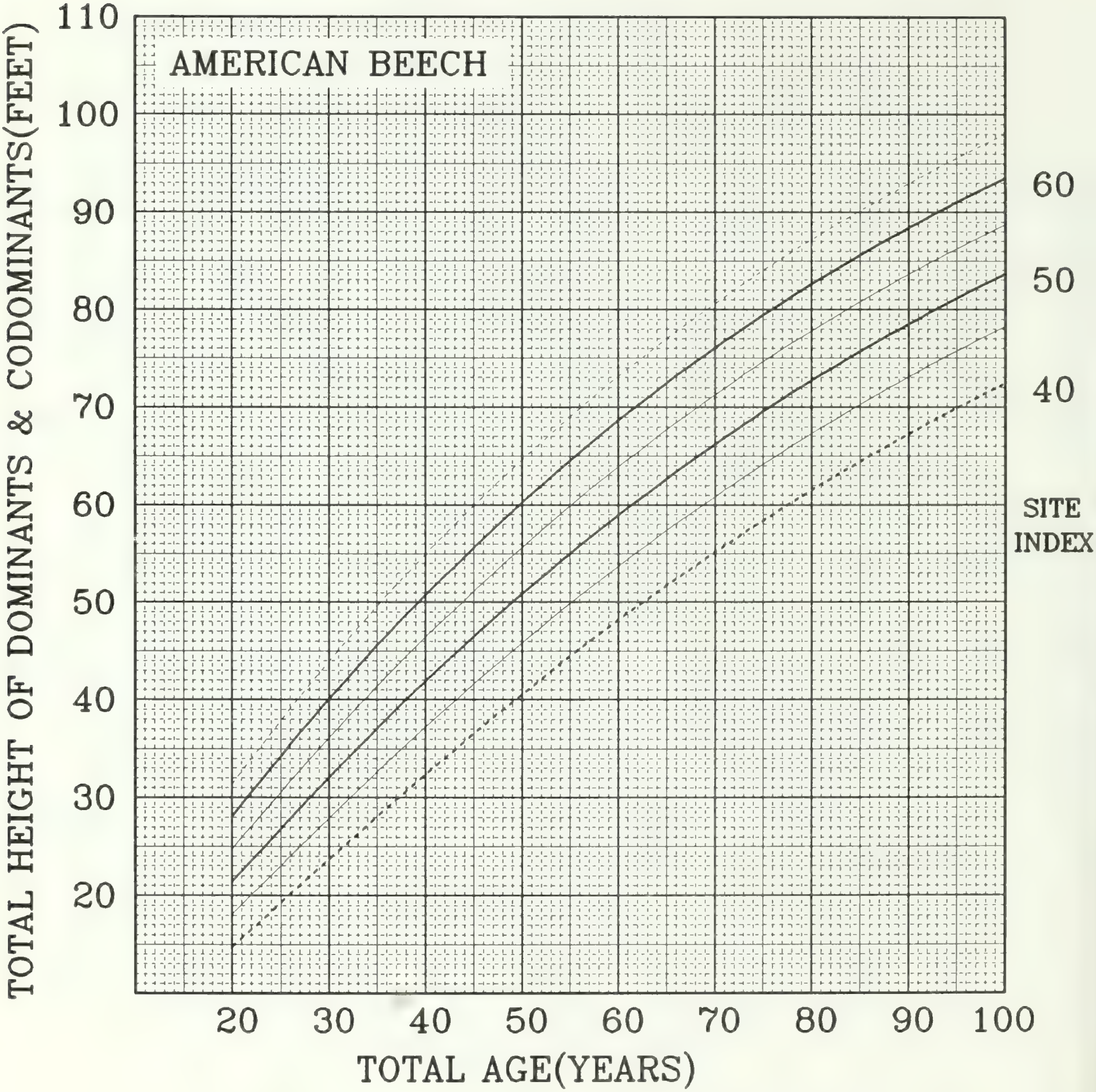

Figure 11.—American beech (Carmean 1978)
Northern Wisconsin and Upper Michigan
19 plots having 70 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	29.7300	0.3631	-0.0127	16.7616	-0.6804	0.99	0.44	1.3
SI	0.2376	1.1312	-0.0109	-1.8550	-0.1430	0.96	1.99	6.5

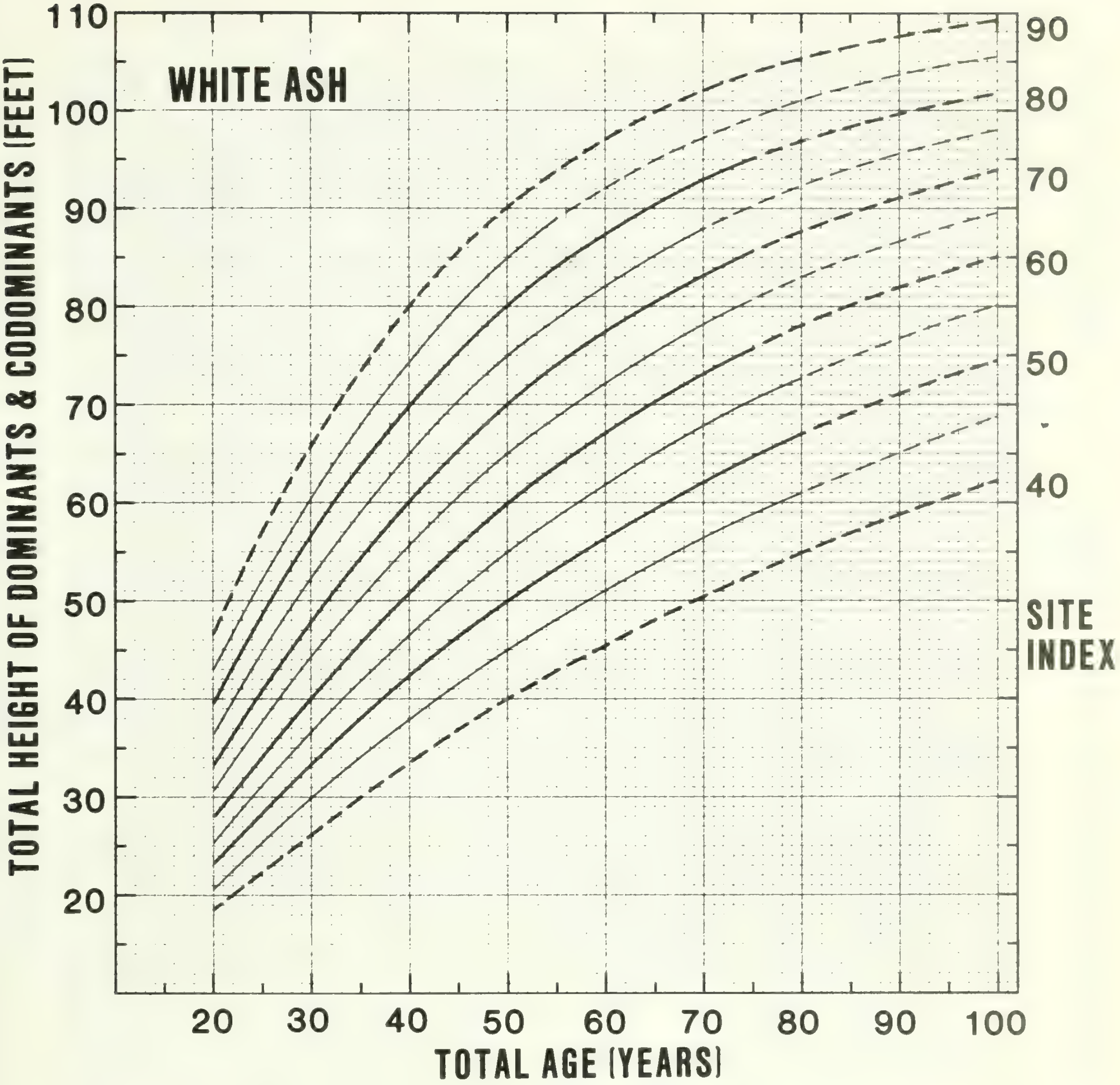

Figure 12.—White ash (Curtis and Post 1962, Solomon 1968)

Vermont Green Mountains

44 plots having 83 dominant and codominant trees

Stem analysis, logarithm equation, anamorphic, original curves redrafted from d.b.h. age to total age and from SI age 75 to SI age of 50

Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5768	0.9978	-0.0156	0.6705	0.0182	0.99	1.77	2.5
SI	0.6835	0.9882	-0.0167	-0.6218	0.0462	0.99	1.70	2.0

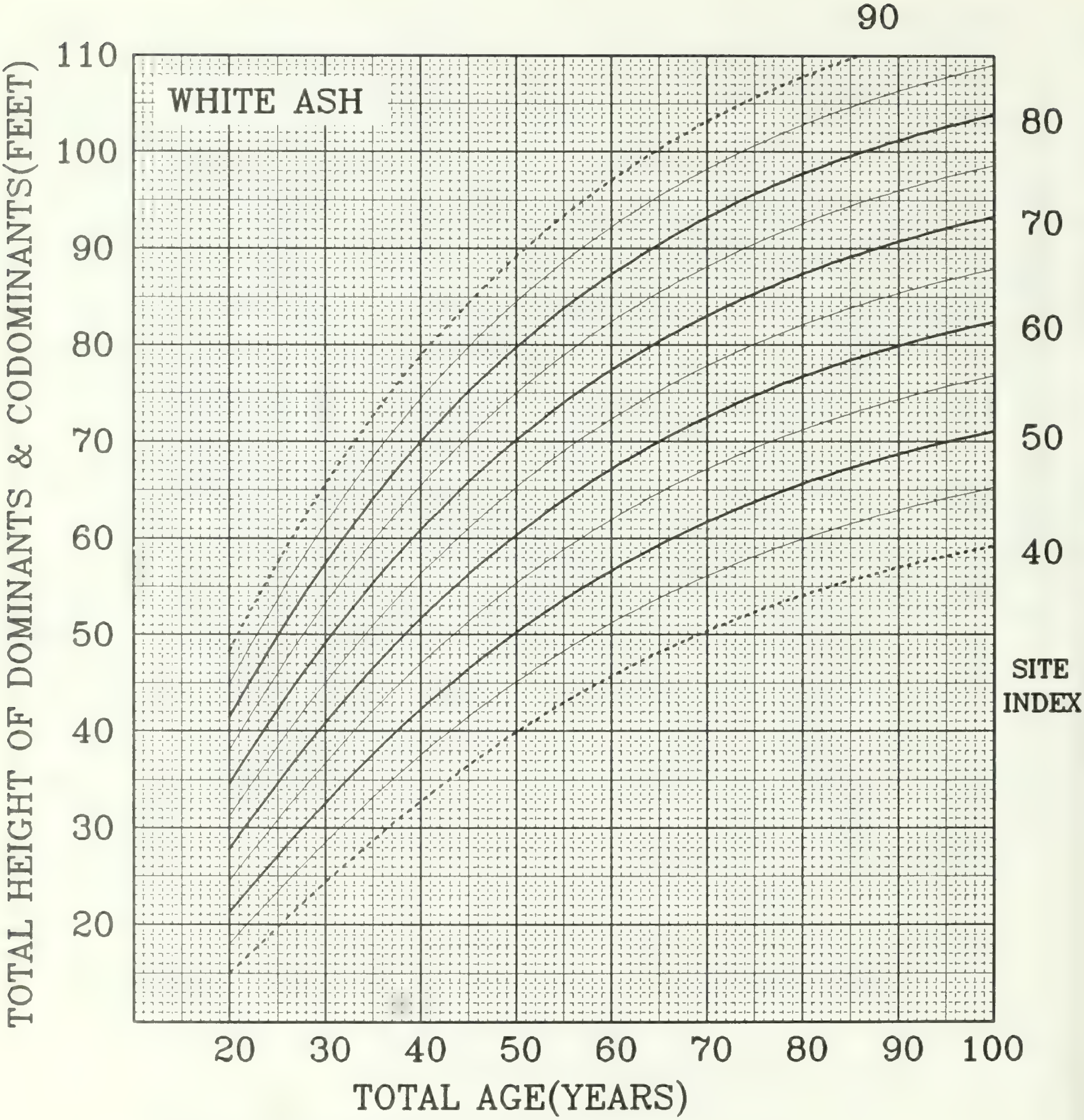

Figure 13.—White ash (Carmean 1978)
Northern Wisconsin and Upper Michigan
73 plots having 275 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.1492	0.7531	-0.0269	14.5384	-0.5811	0.99	1.37	5.1
SI	0.1728	1.2560	-0.0110	-3.3605	-0.3452	0.99	1.99	9.5

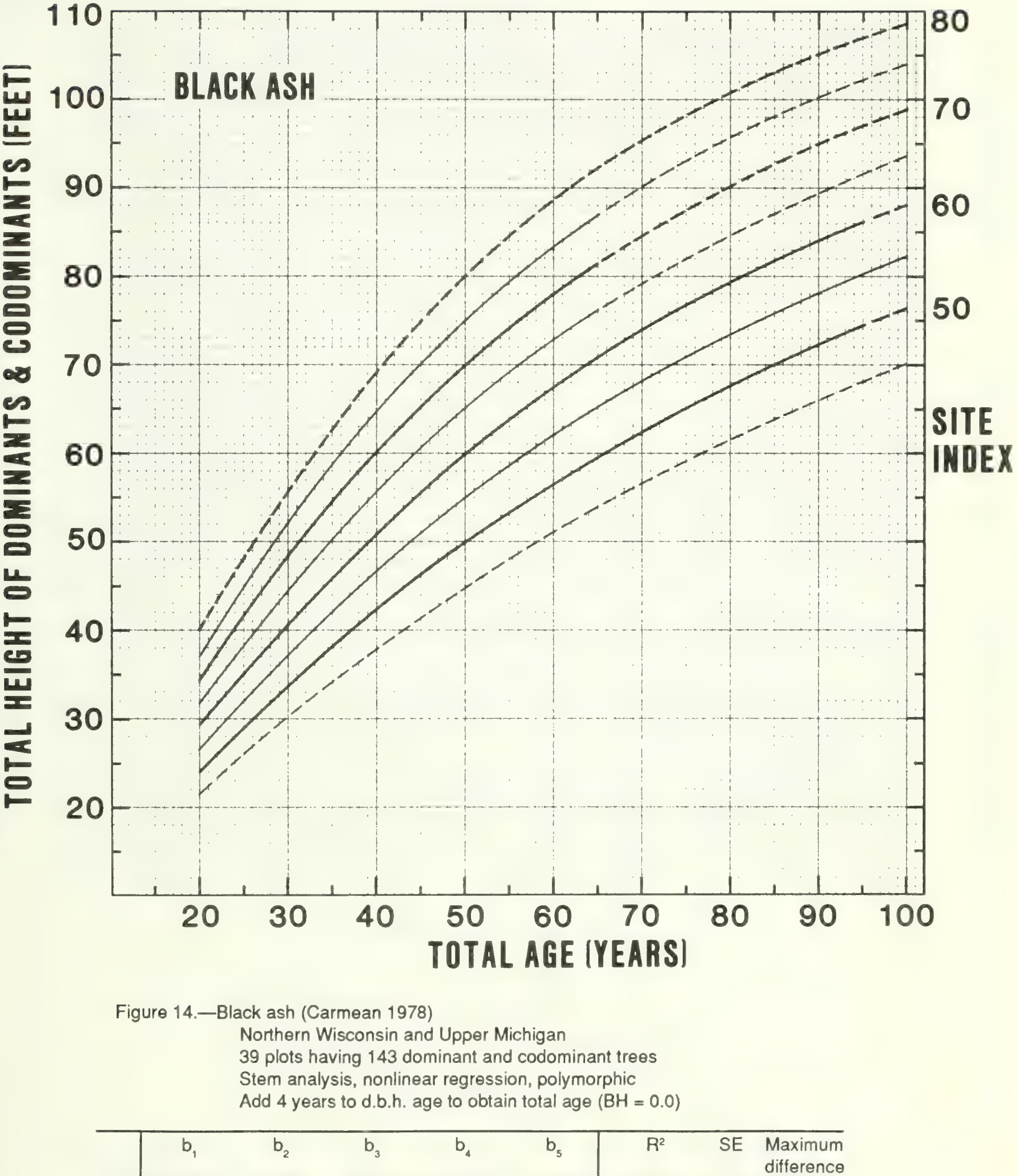

Figure 14.—Black ash (Carmean 1978)
Northern Wisconsin and Upper Michigan
39 plots having 143 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.2286	0.7857	-0.0178	4.6219	-0.3591	0.99	0.70	2.4
SI	0.2388	1.1583	-0.0102	-1.8455	-0.1883	0.99	0.99	3.4

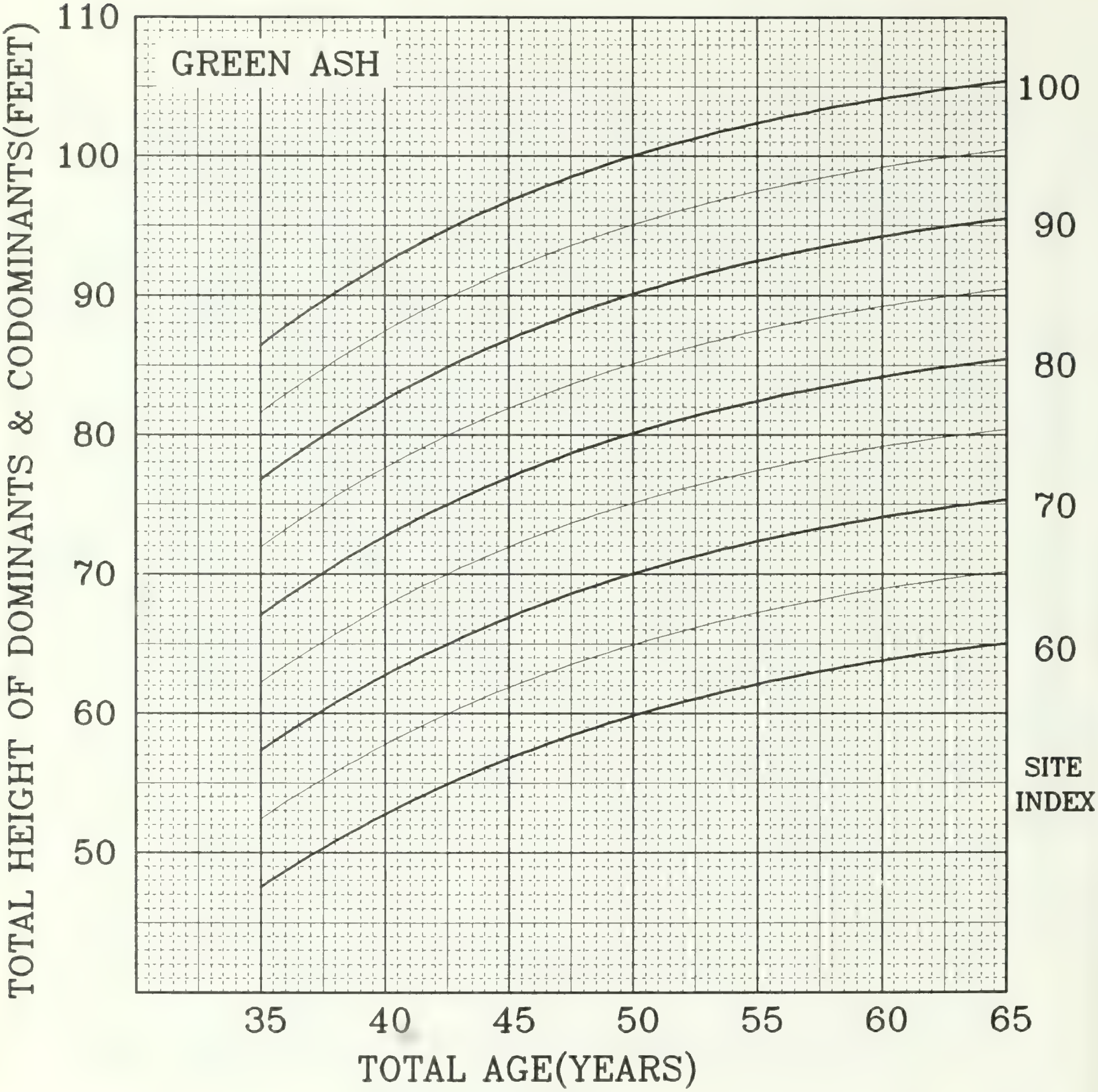

Figure 15.—Green ash (Broadfoot 1969)

Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee

Number of plots and number of dominant and codominant trees not given

Stem analysis, graphically constructed anamorphic curves

Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.6505	0.9096	-0.0644	125.7045	-0.8908	0.99	1.20	0.8
SI	0.5672	1.0990	-0.0482	-38.2659	-0.7549	0.99	1.25	0.8

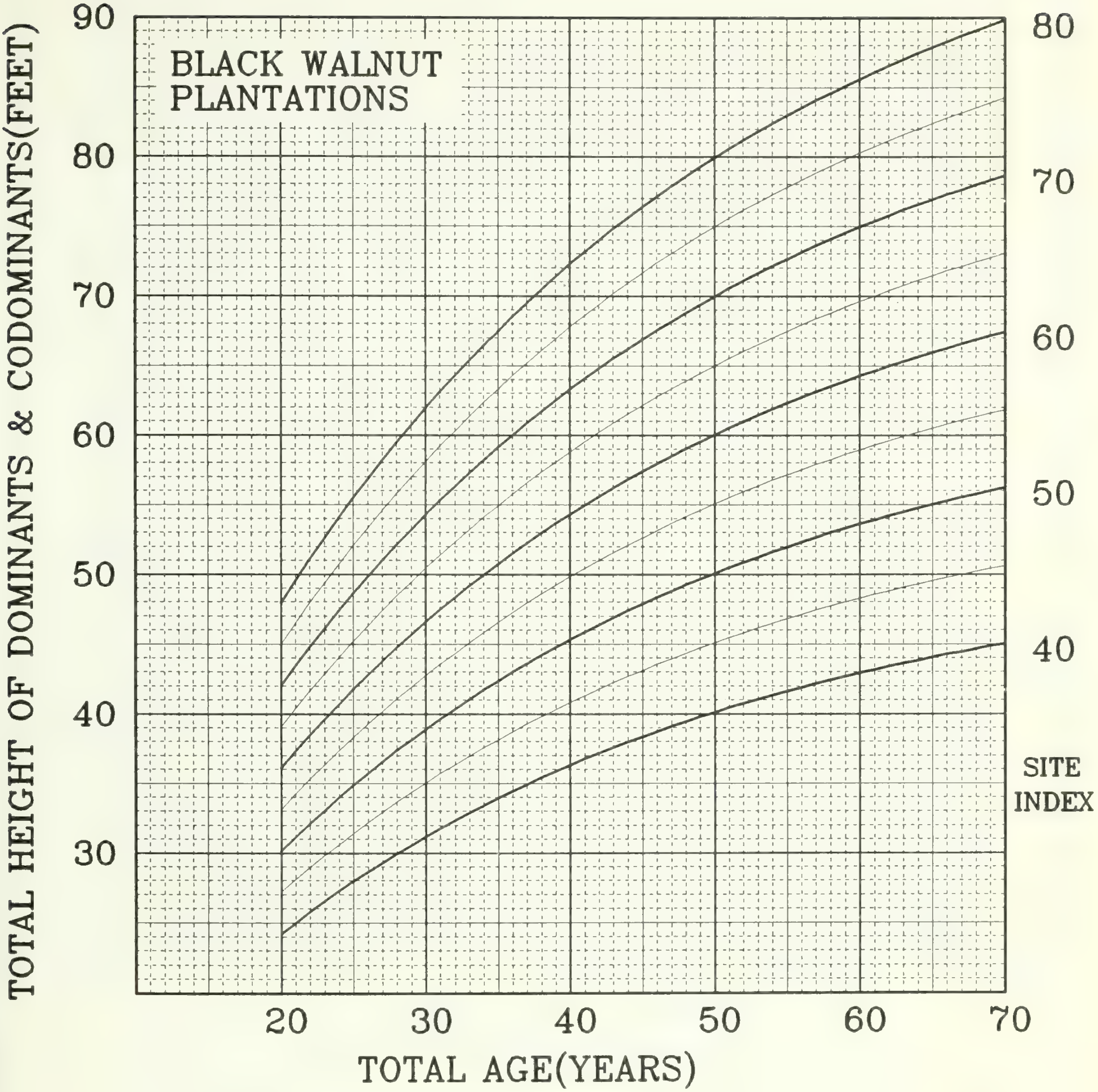

Figure 16.—Black walnut plantations (Kellogg 1939b)
Central States
188 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Determine total age from stumps or planting records (do not damage trees by using an increment borer) (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2898	0.9982	-0.0289	0.8546	0.0171	0.99	0.44	1.7
SI	0.7875	0.9963	-0.0281	-0.7823	0.0353	0.99	0.49	2.1

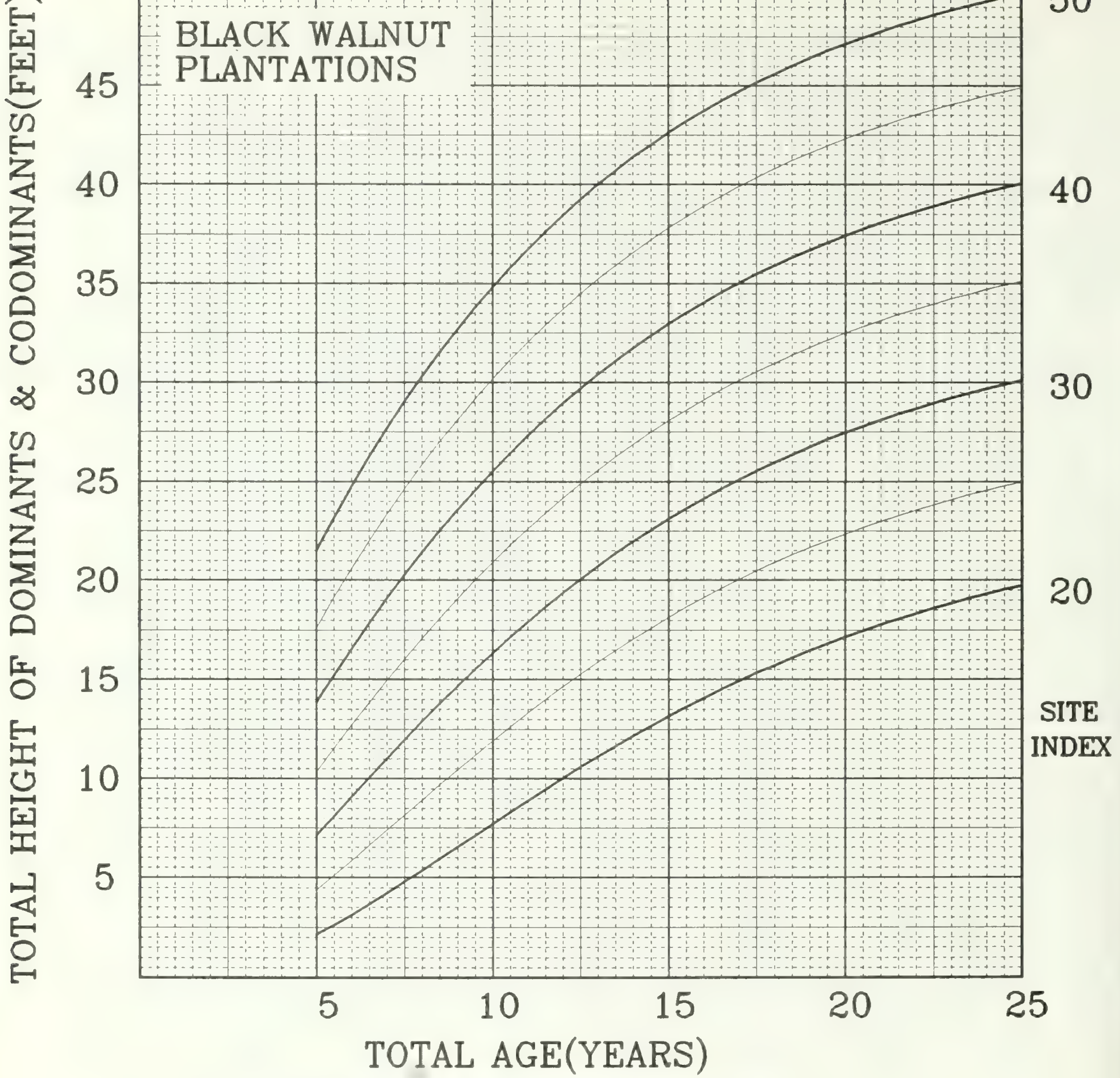

Figure 17.—Black walnut plantations—shallow flood plains (Losche and Schlesinger 1975)

Southern Illinois

19 plots having 85 dominant and codominant trees

Stem analysis, site index prediction equations based on linear regressions using Hegar (1968) model. Site index is height at 25 years total age (BH = 0.0)

Determine total age from stumps or planting records (do not damage trees by using an increment borer)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.6622	0.8860	-0.1113	66.8363	-1.0584	0.99	0.57	1.9
SI	0.6204	1.0542	-0.0373	-1.9626	-0.3491	0.98	1.62	5.4

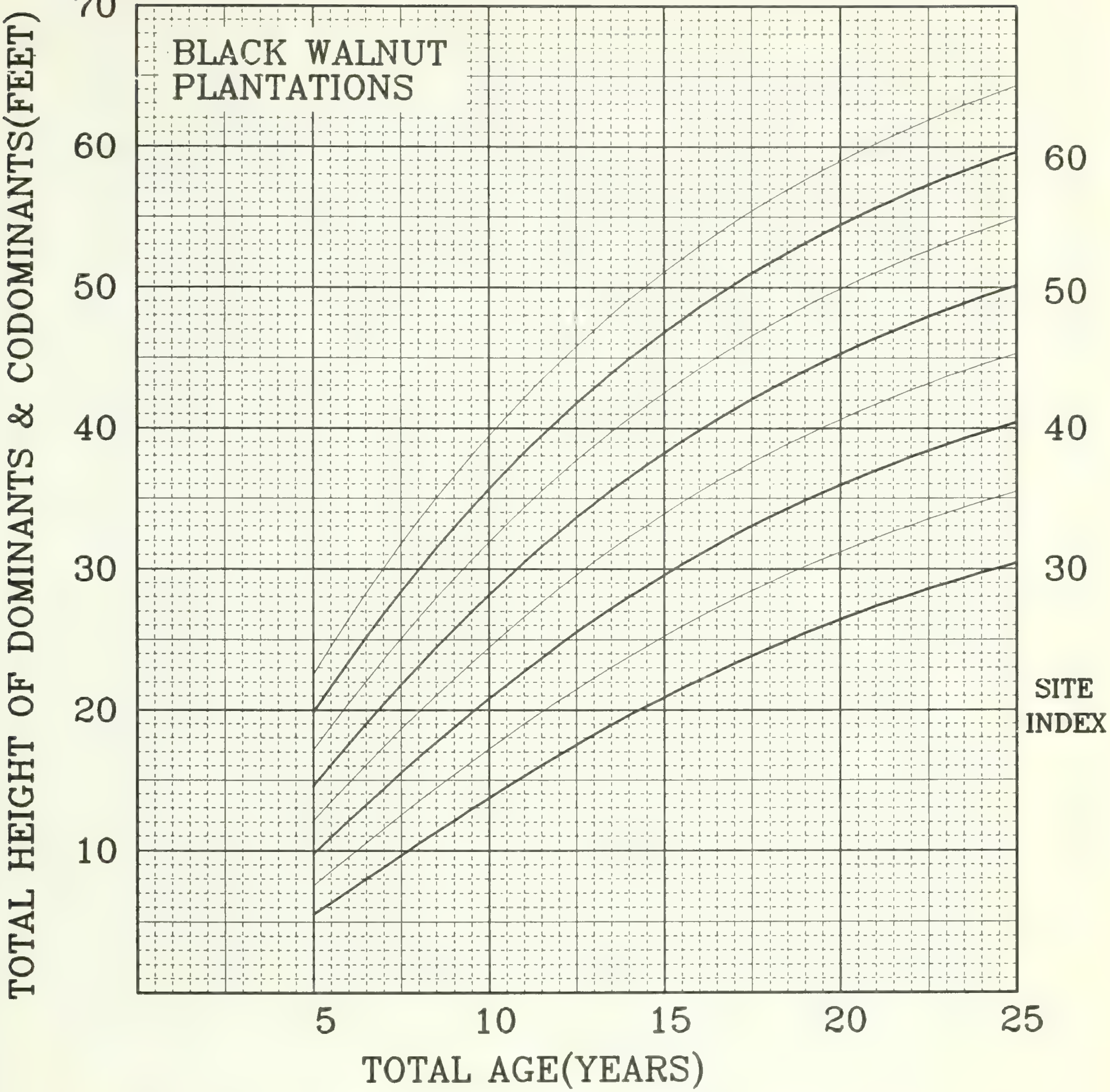

Figure 18.—Black walnut plantations—deep flood plains (Losche and Schlesinger 1975)

Southern Illinois

26 plots having 108 dominant and codominant trees

Stem analysis, site index prediction equations based on linear regressions using Hegar (1968) model. Site index is height at 25 years total age (BH = 0.0)

Determine total age from stumps or planting records (do not damage trees by using an increment borer)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.2349	0.8420	-0.0808	15.0884	-0.6292	0.99	1.10	3.0
SI	0.1758	1.2568	-0.0124	-1.9426	-0.3231	0.98	1.91	5.8

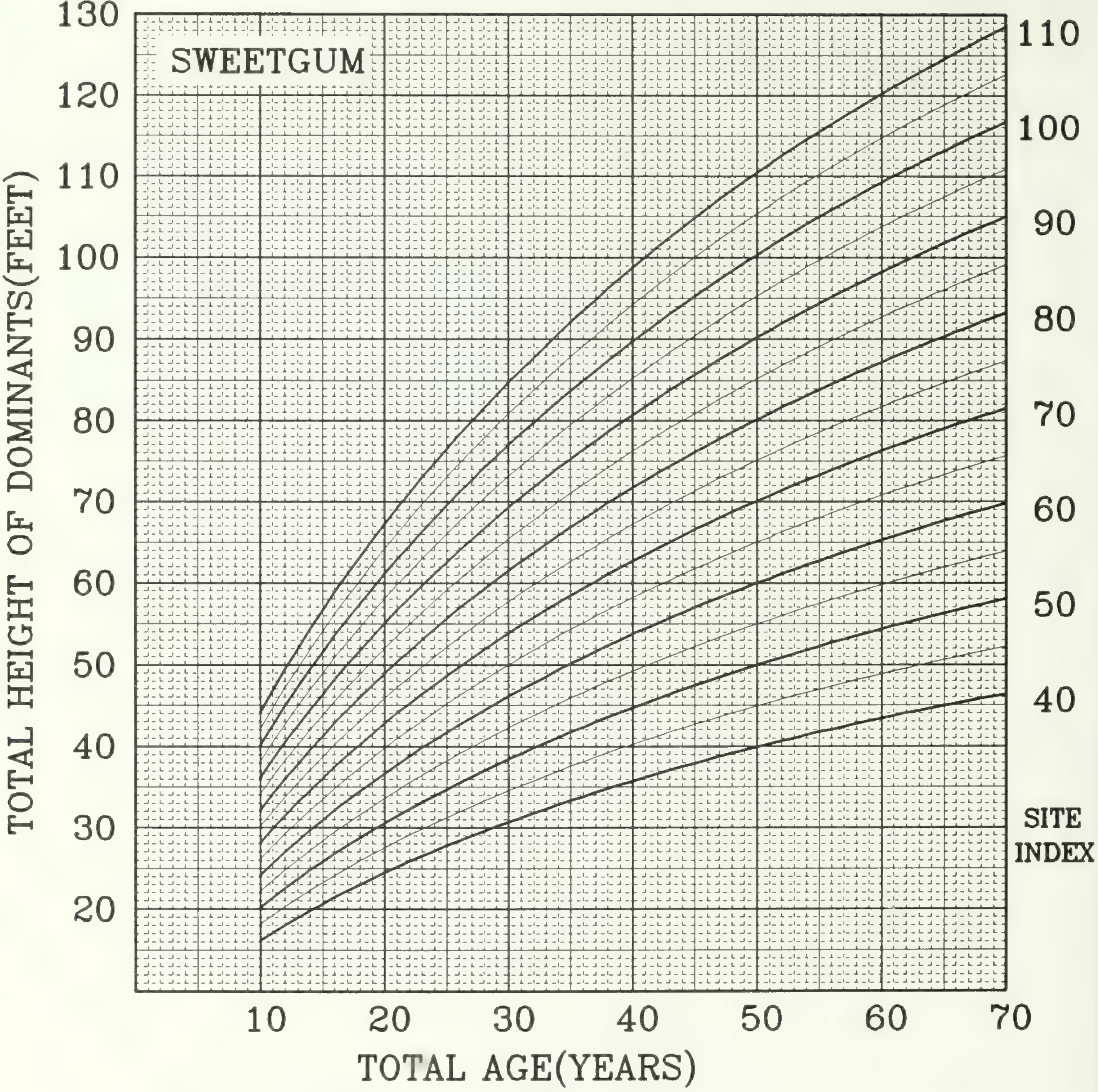

Figure 19.—Sweetgum (Trenk 1929)
Maryland
Number of plots and number of dominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40-55	56-75	76+	
Years:	5	4	3	(seedlings)
	2	1	1	(sprouts)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5932	1.0124	-0.0122	0.6245	0.0130	0.99	0.75	3.3
SI	0.6092	0.9895	-0.0113	-0.6219	0.0078	0.99	1.12	5.5

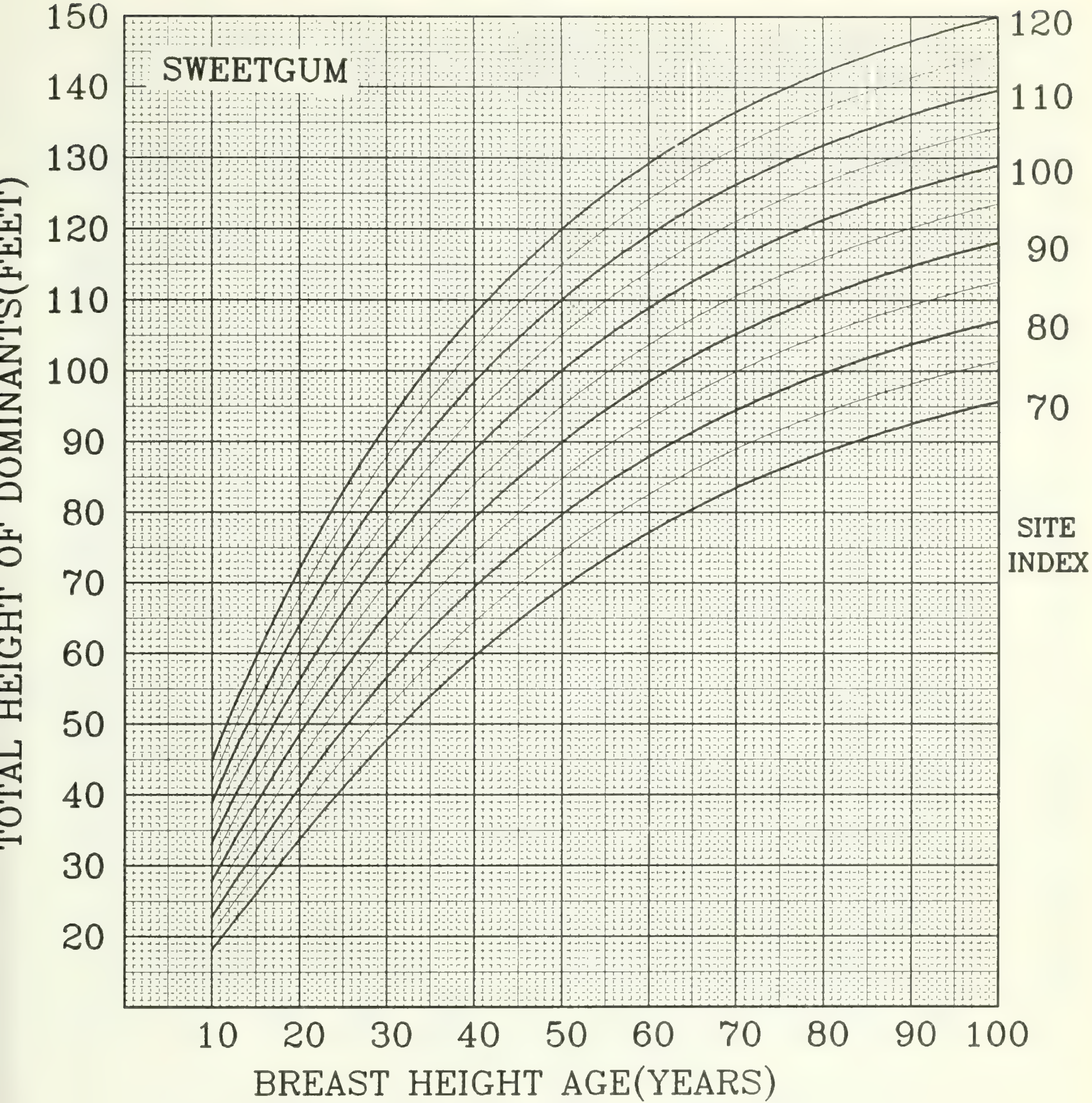

Figure 20.—Sweetgum (Winters and Osbourne 1935)
Mississippi Valley alluvium plus a few locations on alluvial soils of South Carolina, Alabama, and northern Florida
25 locations having 99 plots, number of dominant trees not given (BH = 4.5)
Total height and d.b.h. age, anamorphic, equation not given

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	3.5384	0.7932	-0.0244	29.2355	-0.7291	0.99	1.46	5.2
SI	0.0055	1.6414	-0.0026	-1.7678	-0.2712	0.99	1.86	8.8

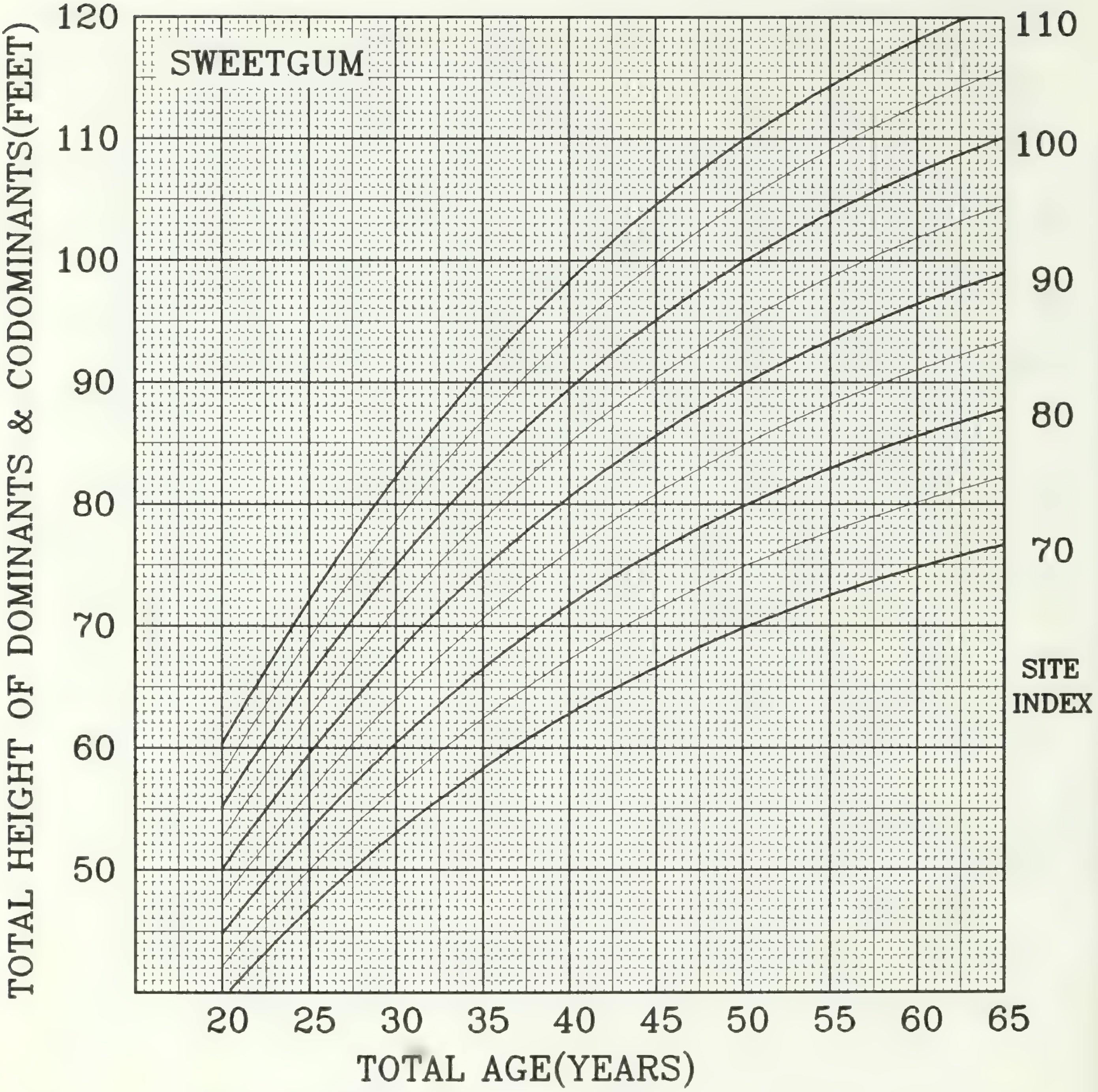

Figure 21.—Sweetgum (Broadfoot and Krinard 1959)
Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee
Number of plots and number of dominant and codominant trees not given
Stem analysis, graphically constructed anamorphic curves
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0902	1.0298	-0.0354	0.7011	0.1178	0.99	0.86	3.9
SI	0.9550	0.9639	-0.0380	-0.6685	0.1478	0.99	0.99	5.1

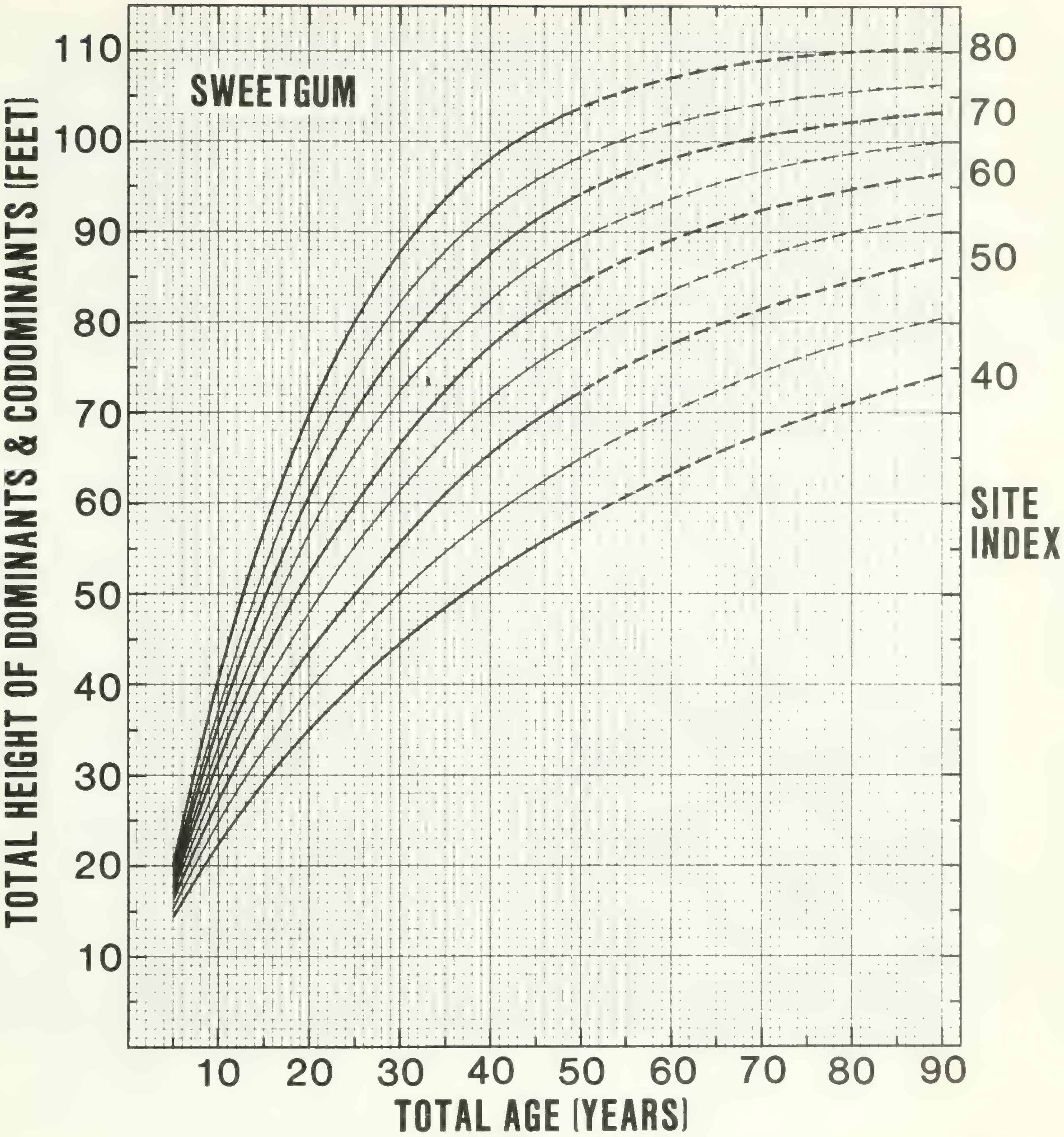

Figure 22.—Sweetgum (Lyle *et al.* 1975)
Alabama
50 stands each having two dominant trees
Stem analysis, nonlinear regression, polymorphic, site index is height at 25 years total age
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.0673	0.6774	-0.0391	9.6135	-0.5504	0.99	2.15	6.7
SI	0.2520	1.1879	-0.0276	-2.0900	-0.2154	0.97	2.61	8.0

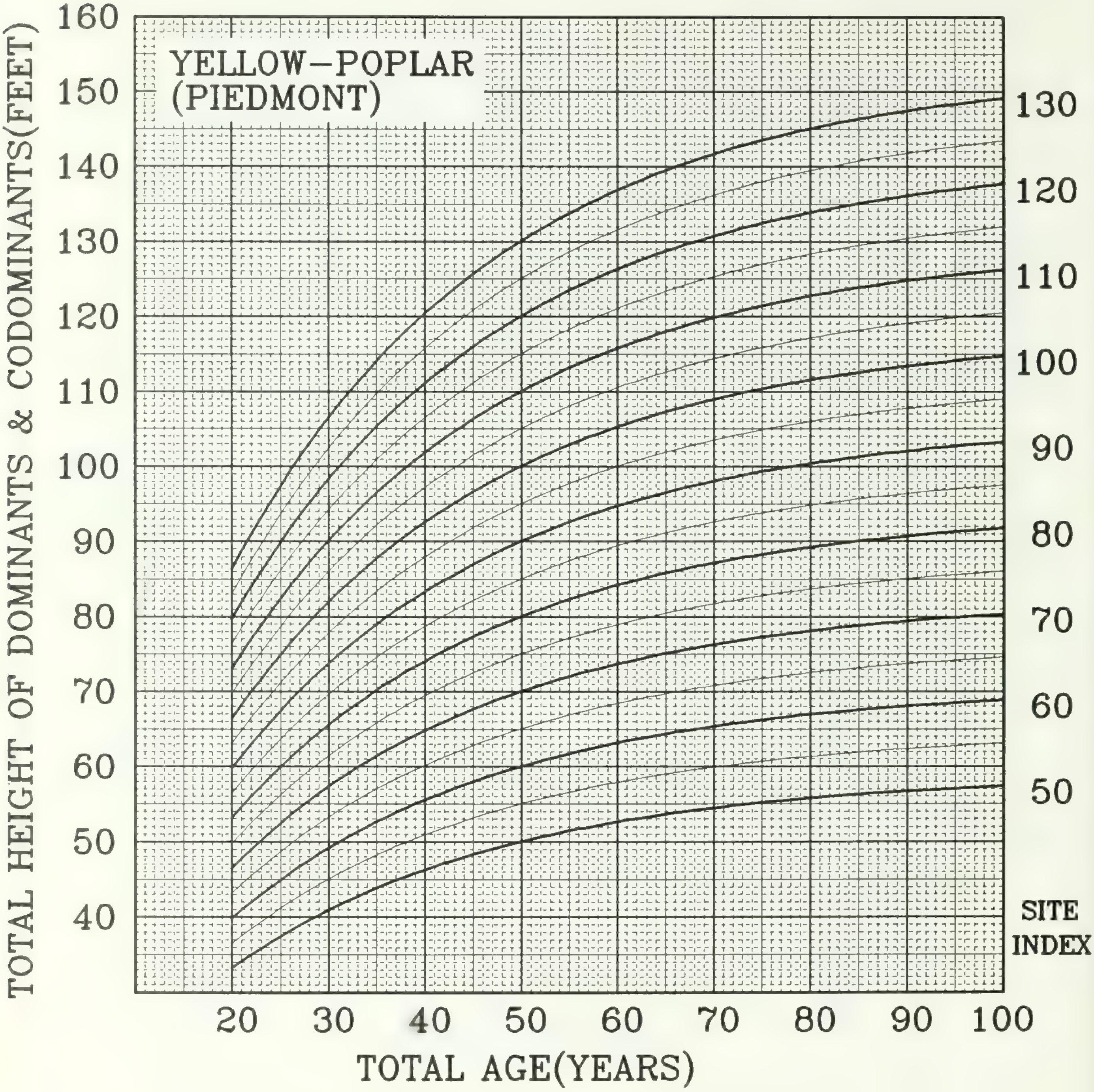

Figure 23.—Yellow-poplar—Piedmont (Beck 1962)
Piedmont of Carolinas and Virginia
117 plots having 4 to 6 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1798	1.0000	-0.0339	0.8117	-0.0001	0.99	0.78	3.3
SI	0.8323	1.0051	-0.0352	-0.9706	-0.0303	0.99	0.86	4.0

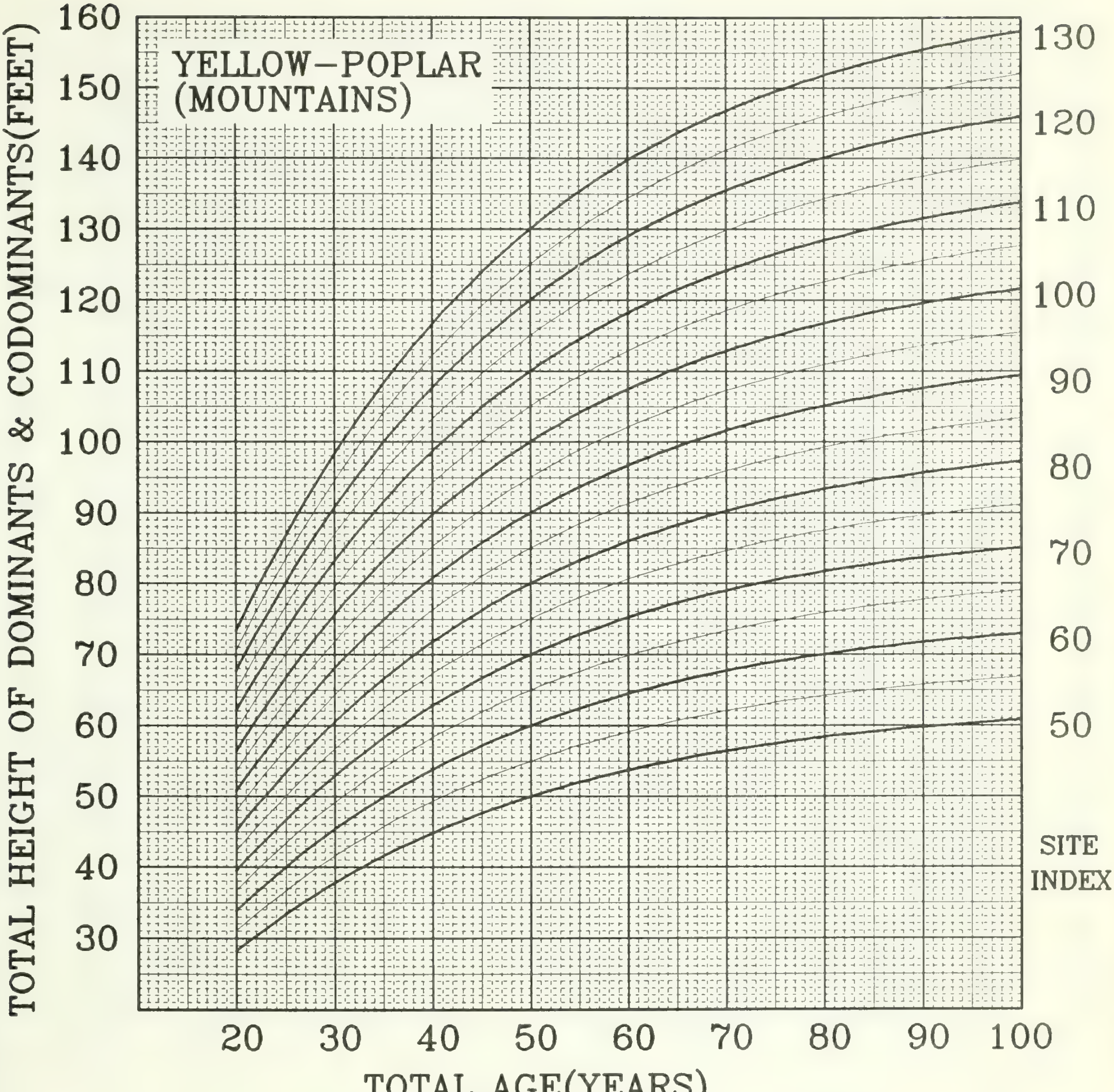

Figure 24.—Yellow-poplar—Mountains (Beck 1962)

Southern Appalachians of western North Carolina and northern Georgia

267 plots having 4 to 6 dominant and codominant trees on each plot

Total height and total age, anamorphic, logarithm equation

Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2673	1.0000	-0.0331	1.1149	0.0001	0.99	1.02	4.3
SI	0.7609	1.0097	-0.0346	-1.4002	-0.0402	0.99	1.18	5.6

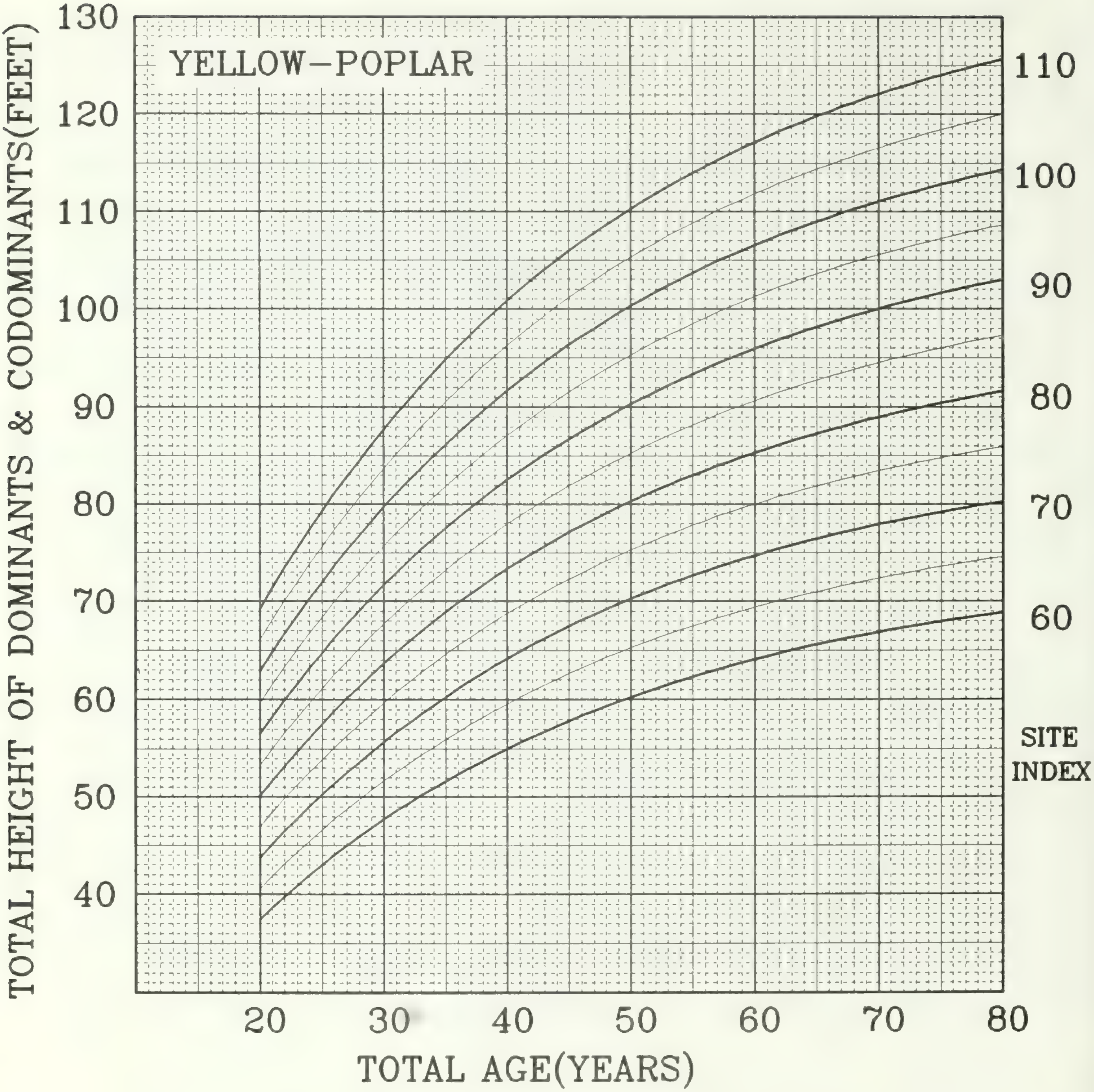

Figure 25.—Yellow-poplar (Schlaegel, Kulow, and Baughman 1969)
West Virginia Appalachians
123 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, logarithm equation
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2941	0.9892	-0.0315	-1.0471	-0.0368	0.99	1.18	2.1
SI	0.7459	1.0184	-0.0313	-1.2121	-0.0717	0.99	1.21	2.4

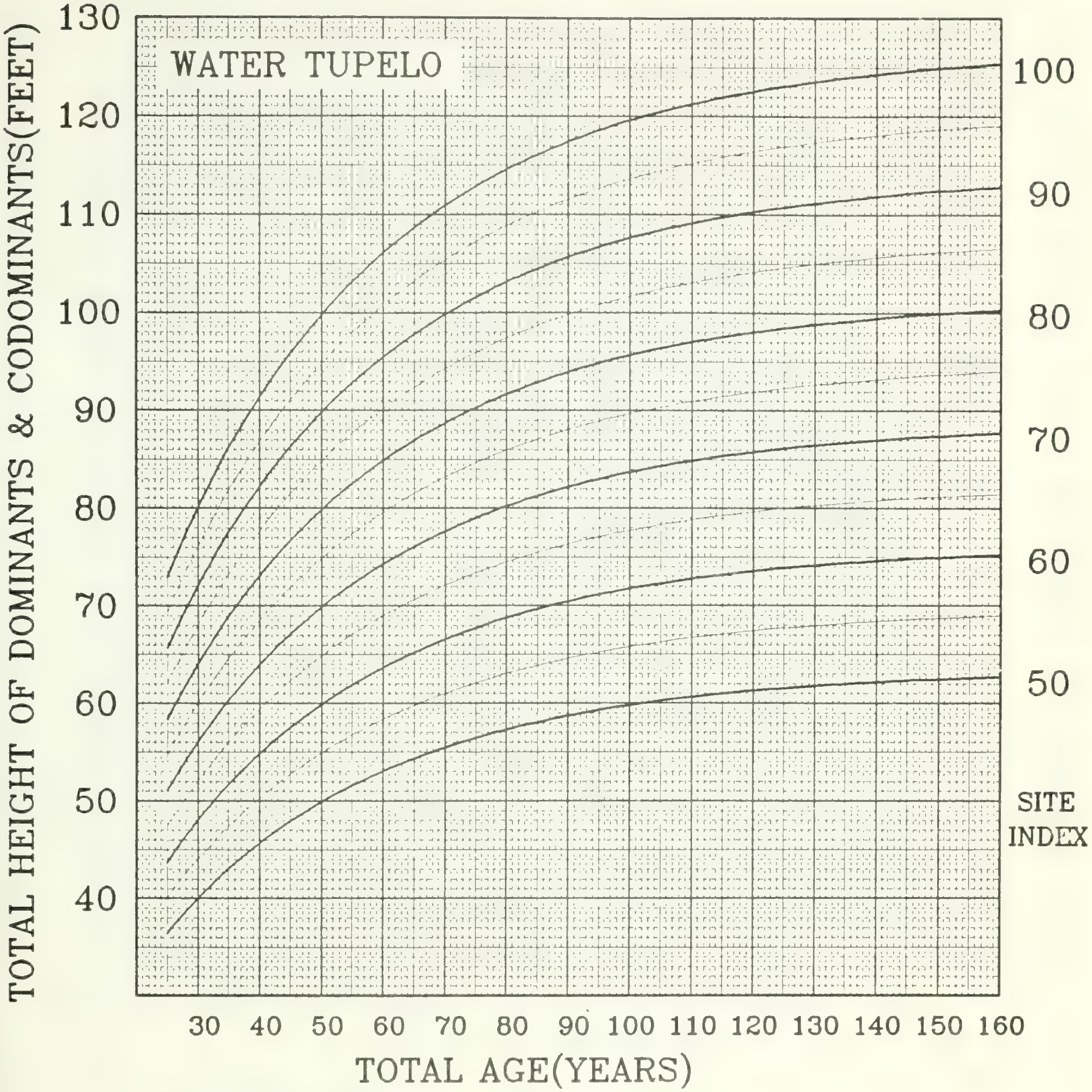

Figure 26.—Water tupelo (Applequist 1959)
Lower coastal plain of southeastern Georgia
17 plots having 6 to 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2721	0.9995	-0.0256	0.7447	-0.0019	0.99	0.59	4.4
SI	0.7505	1.0112	-0.0259	-0.9213	-0.0475	0.99	0.60	3.0

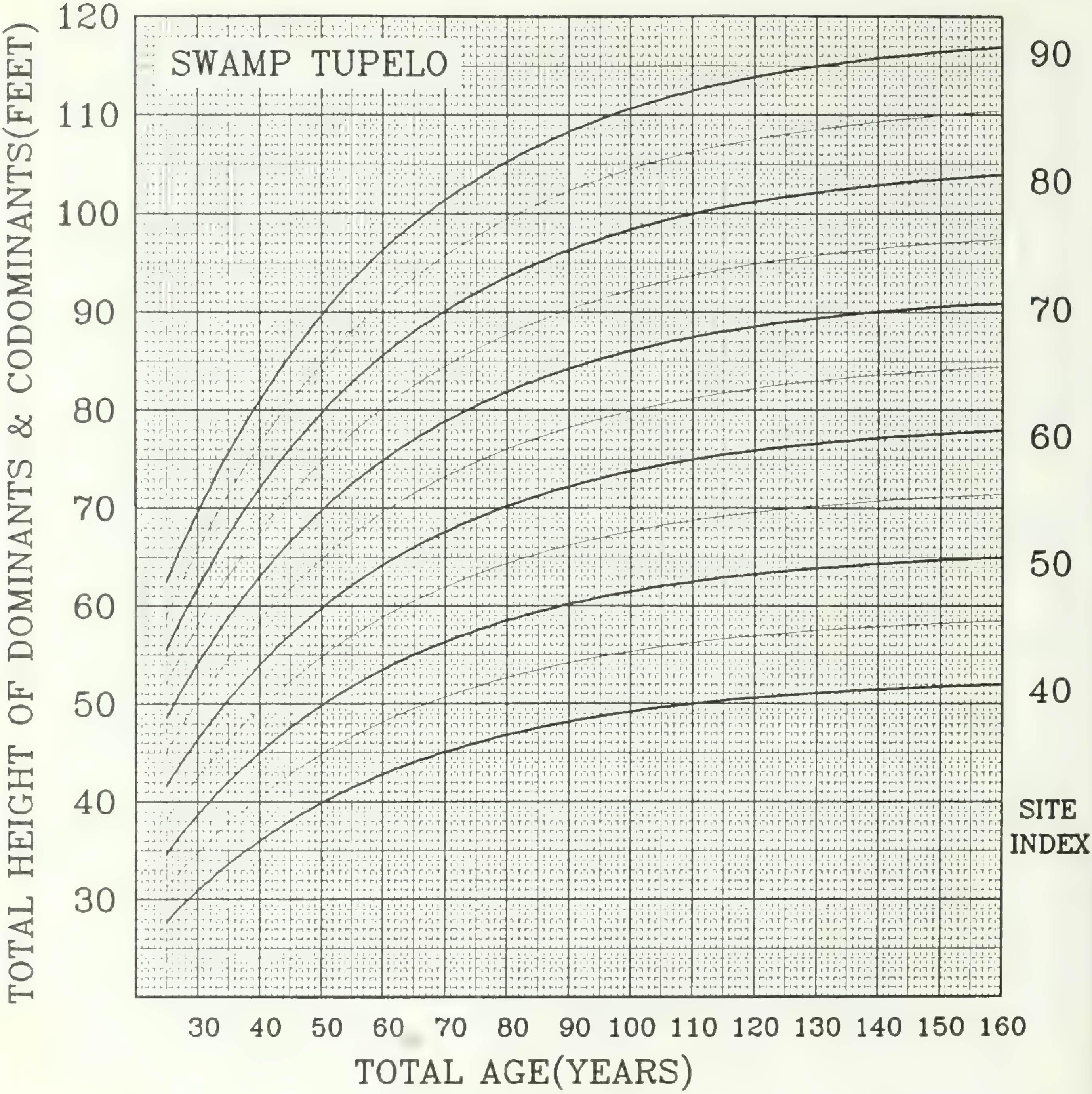

Figure 27.—Swamp tupelo (Applequist 1959)
Lower coastal plain of southeastern Georgia
81 plots having 6 to 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3213	0.9995	-0.0254	0.8549	-0.0016	0.99	0.59	2.4
SI	0.7224	1.0117	-0.0259	-1.0375	-0.0428	0.99	0.61	3.0

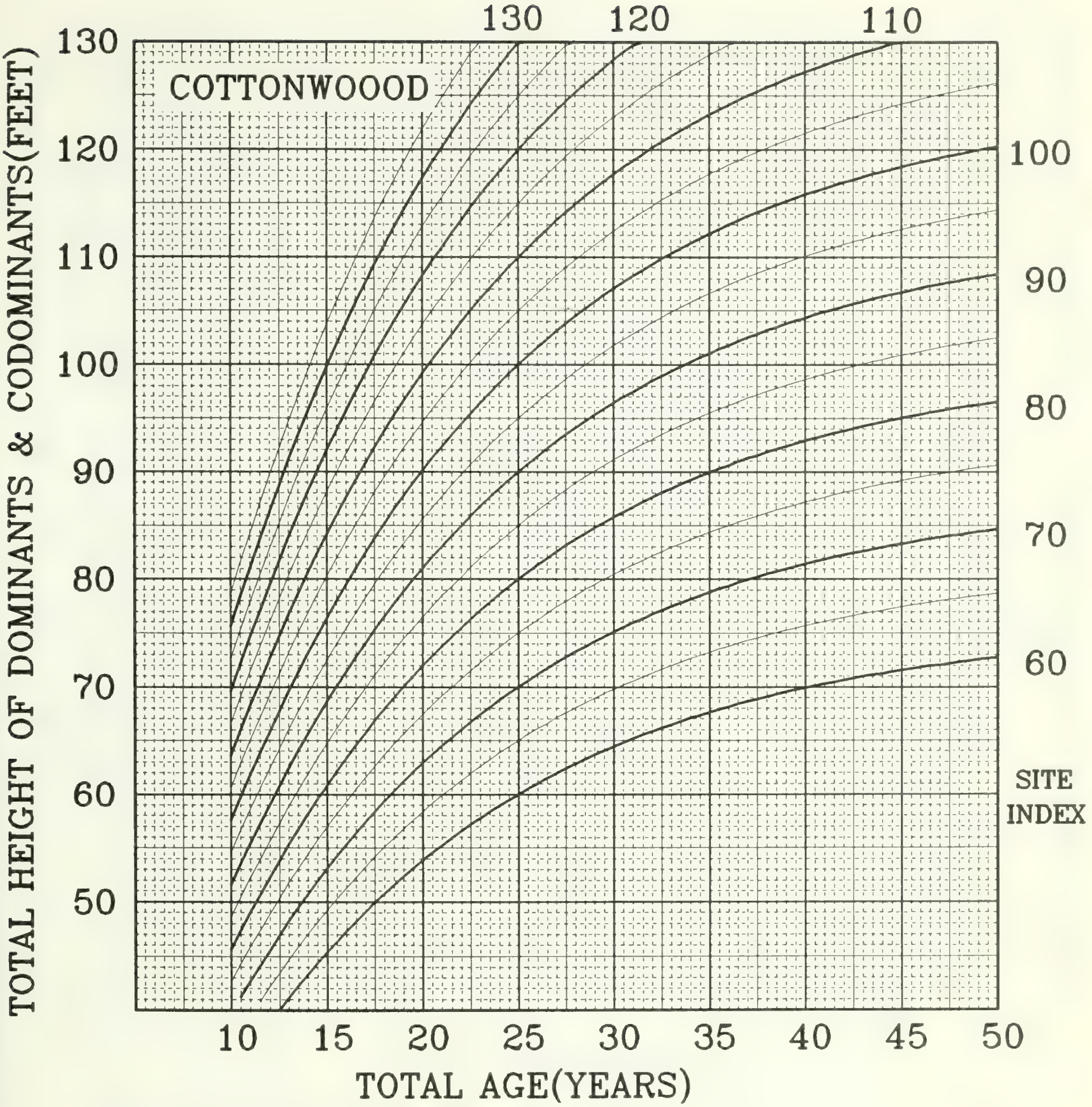

Figure 28.—Cottonwood (Neebe and Boyce 1959)
Southern Illinois bottomlands and a few uplands
65 areas having 172 dominant and codominant trees
Total height and total age, anamorphic, site index prediction
using straight line "curves," equation not given
Site index is total height at 25 years total age
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3615	0.9813	-0.0675	1.5494	-0.0767	0.99	1.06	3.1
SI	0.6901	1.0316	-0.0655	-1.8288	-0.1226	0.99	1.05	3.3

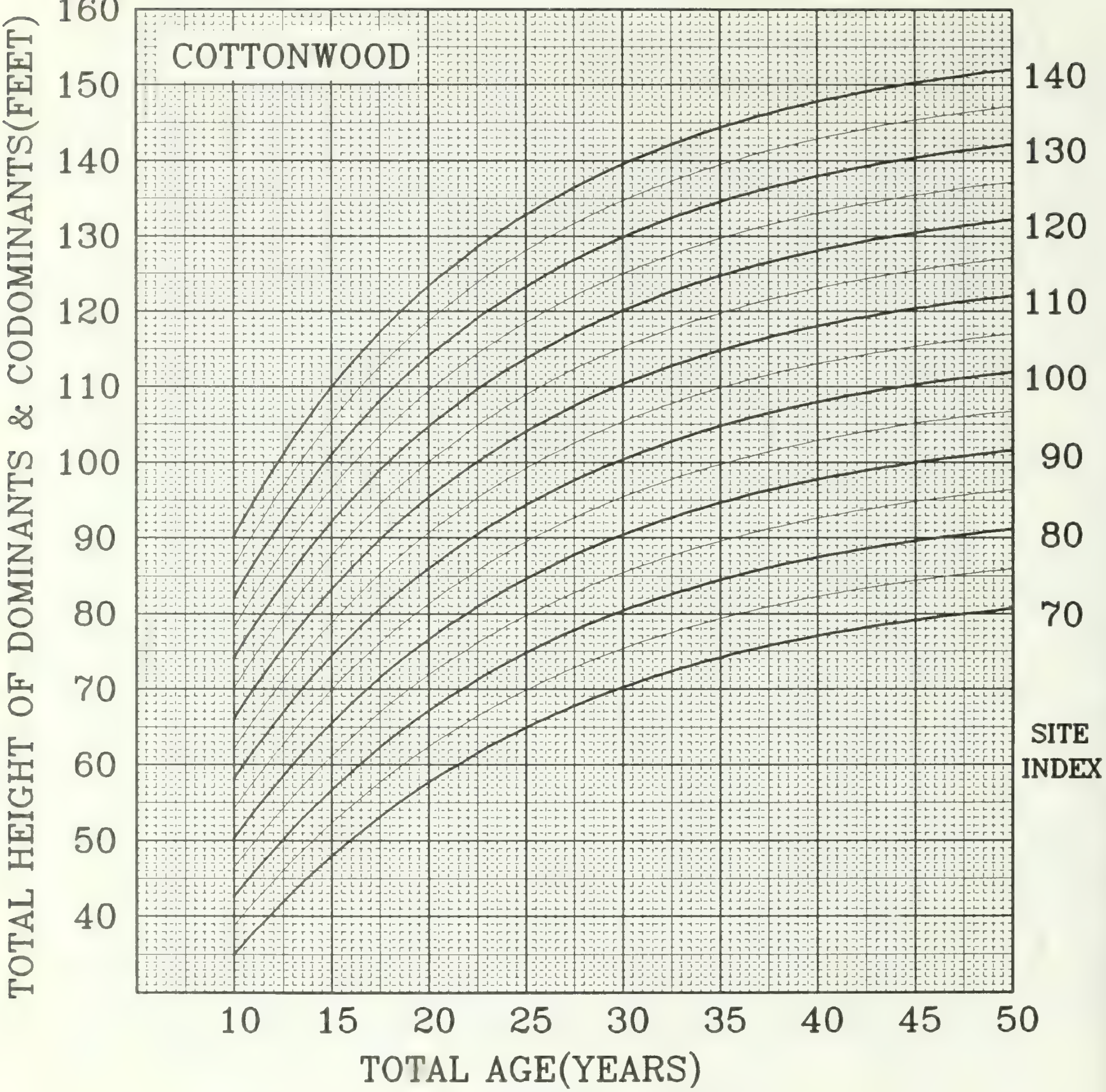

Figure 29.—Cottonwood (Broadfoot 1960)

Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee, Missouri, Kentucky

Number of plots and number of dominant and codominant trees not given

Stem analysis, graphically constructed anamorphic curves, site index is height at 30 years total age

Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.9426	0.8886	-0.0640	21.0753	-0.6786	0.99	0.90	3.4
SI	0.4754	1.1190	-0.0429	-5.6452	-0.4912	0.99	1.64	4.8

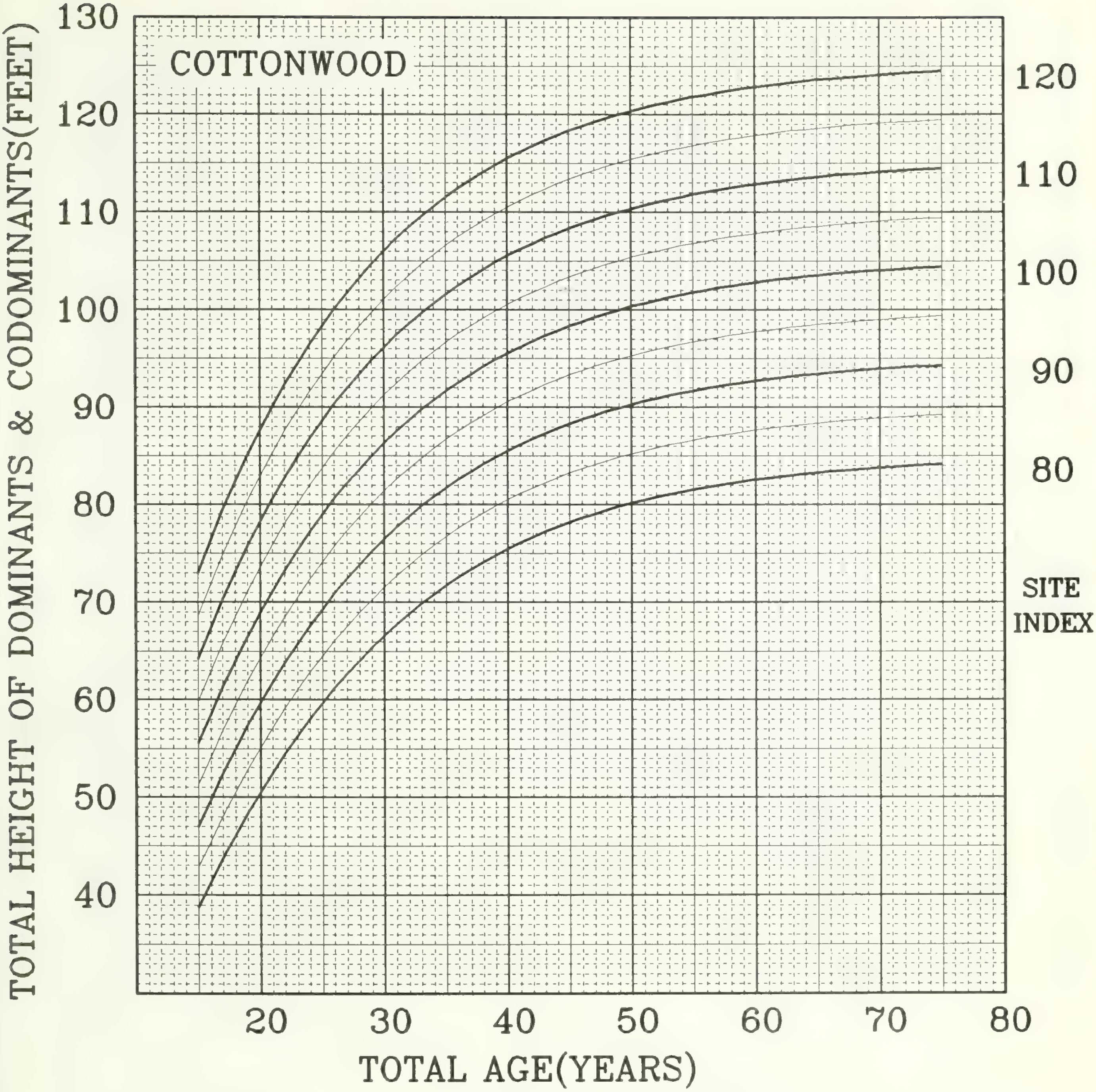

Figure 30.—Cottonwood (Brendemuehl 1965)
Iowa bottomlands
66 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2834	0.9571	-0.0680	100.0000	-0.9223	0.99	0.96	3.3
SI	0.7688	1.0412	-0.0462	-14.4222	-0.6595	0.99	1.56	4.4

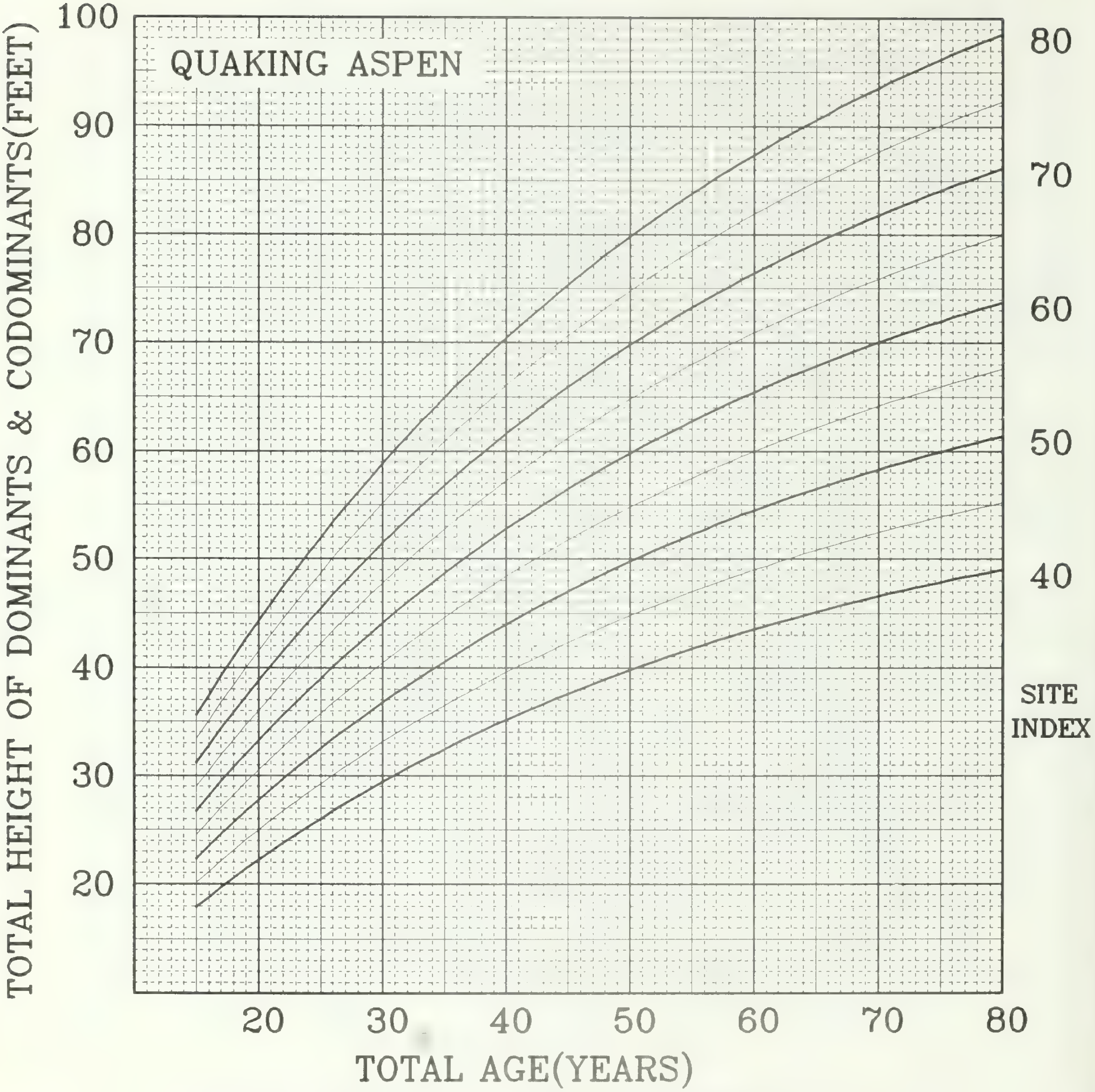

Figure 31.—Quaking aspen (Gevorkiantz 1956a, from Kittredge and Gevorkiantz 1929)

Number of plots and number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4475	1.0098	-0.0200	0.8489	0.0146	0.99	0.15	0.4
SI	0.6755	1.0000	-0.0213	-0.9367	-0.0002	0.99	0.04	0.1

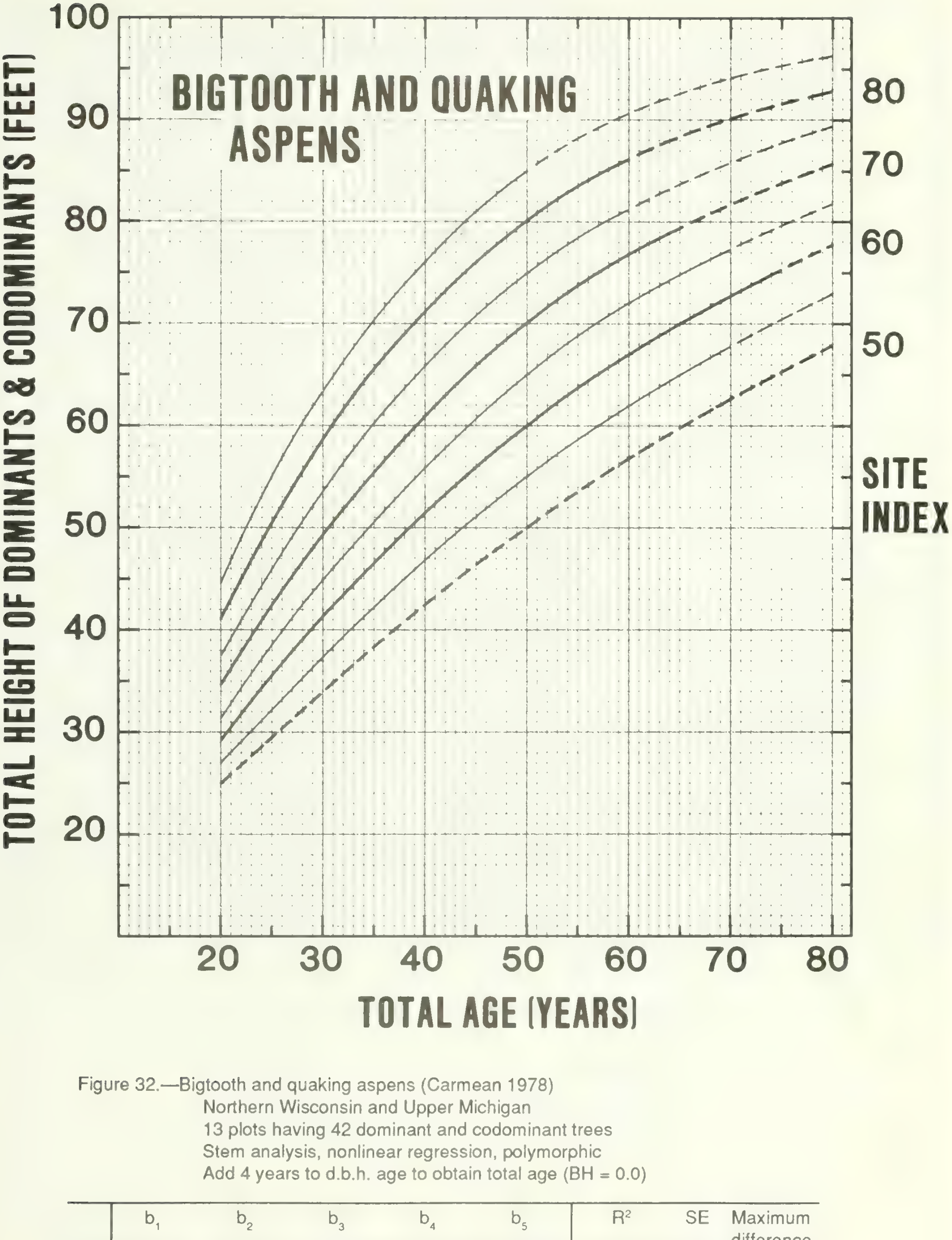

Figure 32.—Bigtooth and quaking aspens (Carmean 1978)
Northern Wisconsin and Upper Michigan
13 plots having 42 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	5.2188	0.6855	-0.0301	50.0071	-0.8695	0.99	1.58	4.5
SI	0.0612	1.4390	-0.0050	-3.9080	-0.4350	0.99	1.90	10.4

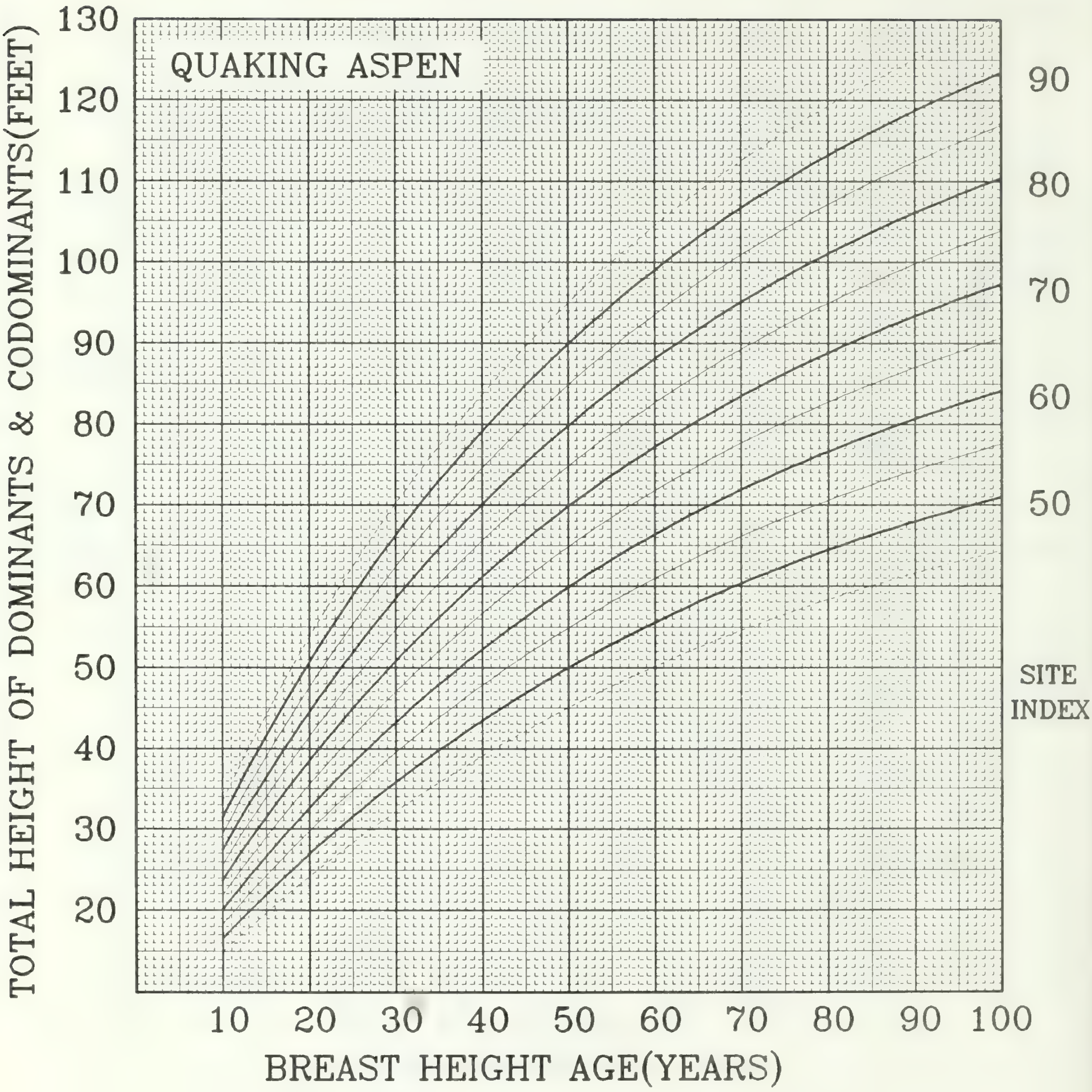

Figure 33.—Quaking aspen (Deschamps 1989)
North central Ontario
99 plots having 3 dominant and codominant trees per plot
Stem analysis, nonlinear regression, polymorphic
Site index is total height at 50 years breast height age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.1567	0.9374	-0.0155	2.4997	-0.2338	0.98	0.51	0.3
SI	0.2356	1.1332	-0.0082	-1.0342	-1.0772	0.99	1.01	2.7

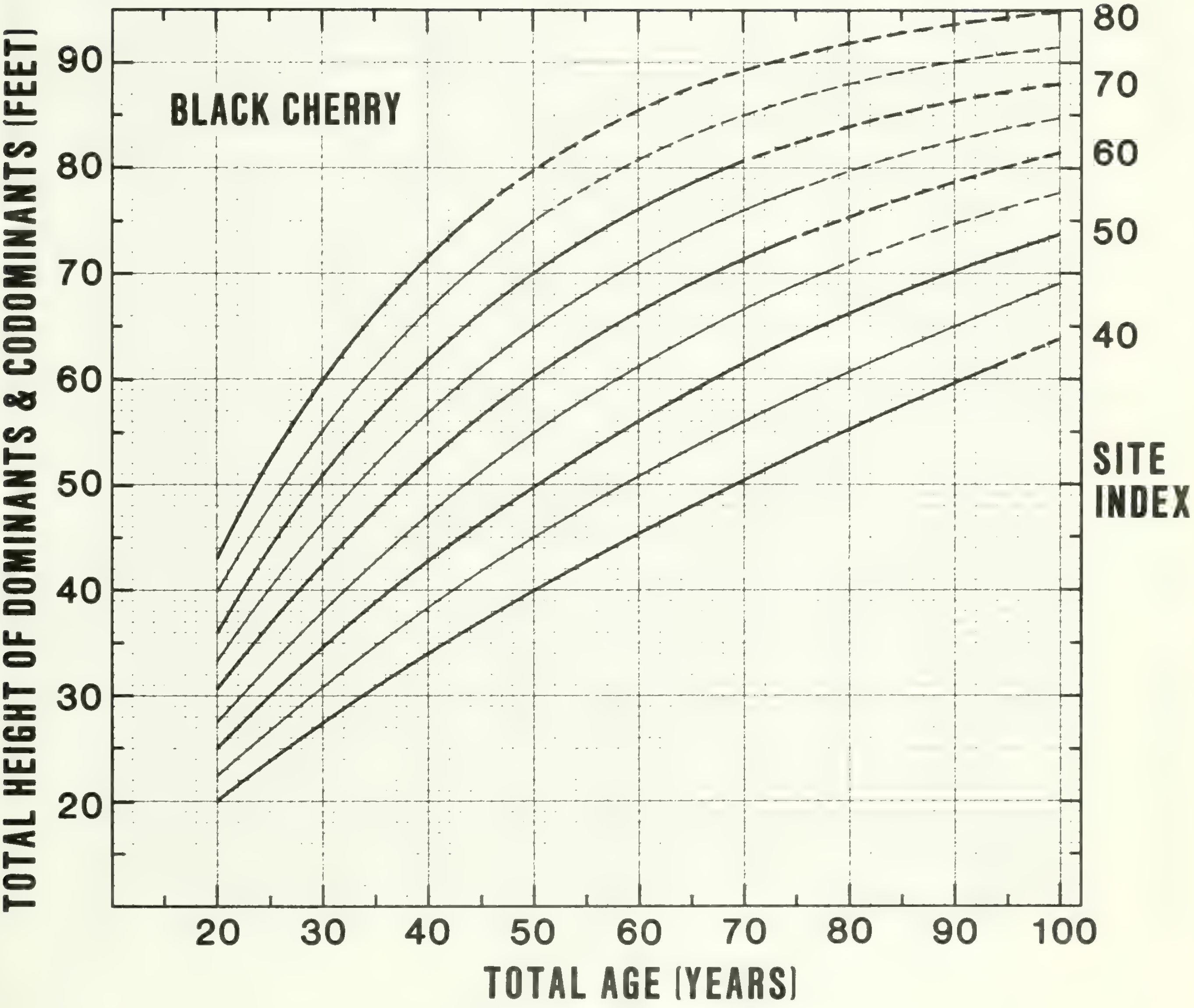

Figure 34.—Black cherry (Carmean 1978)
Northern Wisconsin and Upper Michigan
42 plots having 126 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	5.1493	0.6948	-0.0248	20.9210	-0.7143	0.99	1.55	5.4
SI	0.1073	1.3455	-0.0070	-3.3034	-0.3899	0.99	1.77	9.1

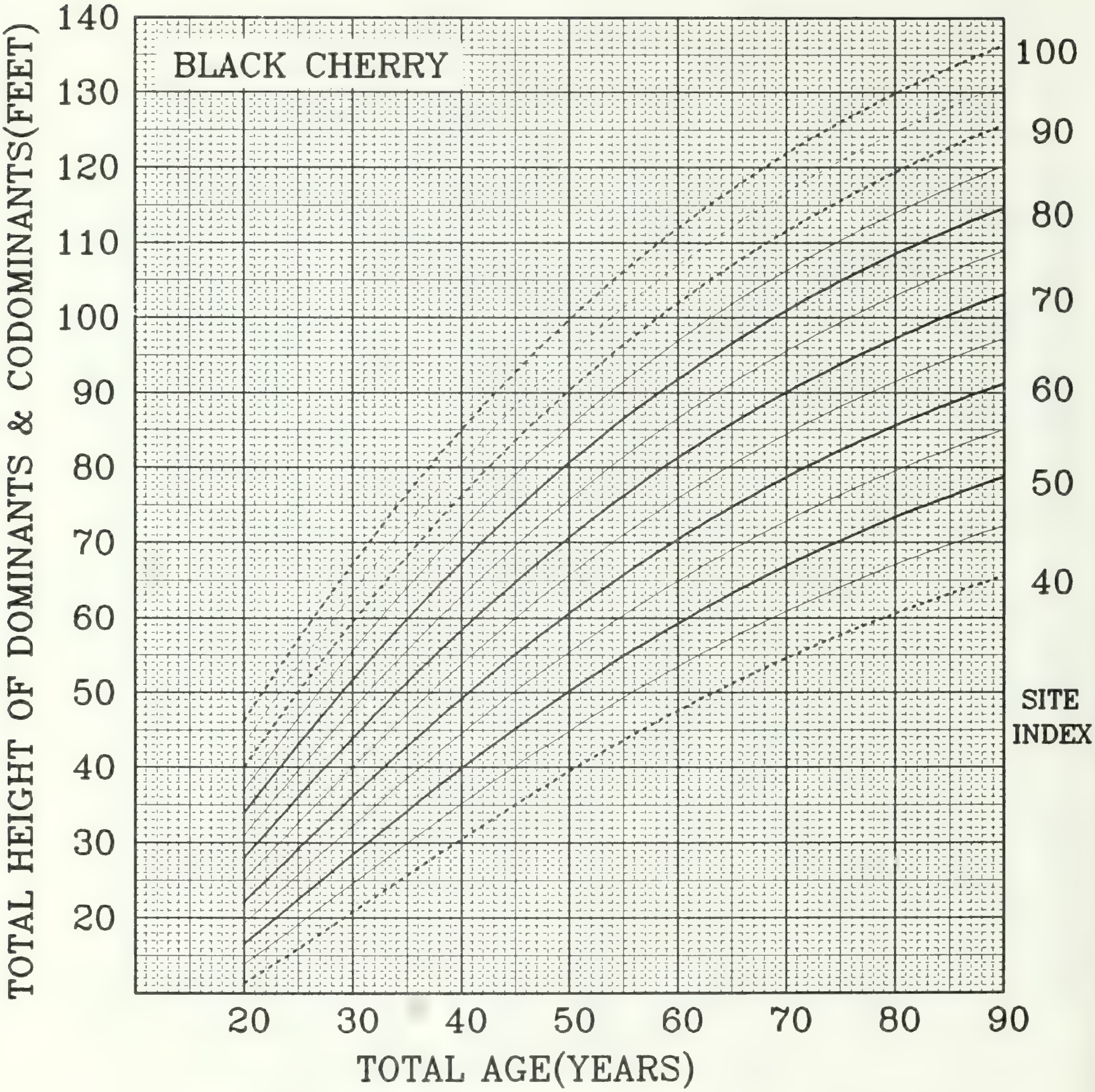

Figure 35.—Black cherry (Auchmoody and Rexrode 1984)
Northwestern Pennsylvania Allegheny Plateau
6 stands having 39 dominant and codominant trees
Stem analysis, site index prediction equations based on second degree quadratic regressions
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	7.1846	0.6781	-0.0222	13.9186	-0.5268	0.99	1.54	4.4
SI	0.0063	1.6337	-0.0010	-2.4168	-0.2635	0.99	2.39	6.9

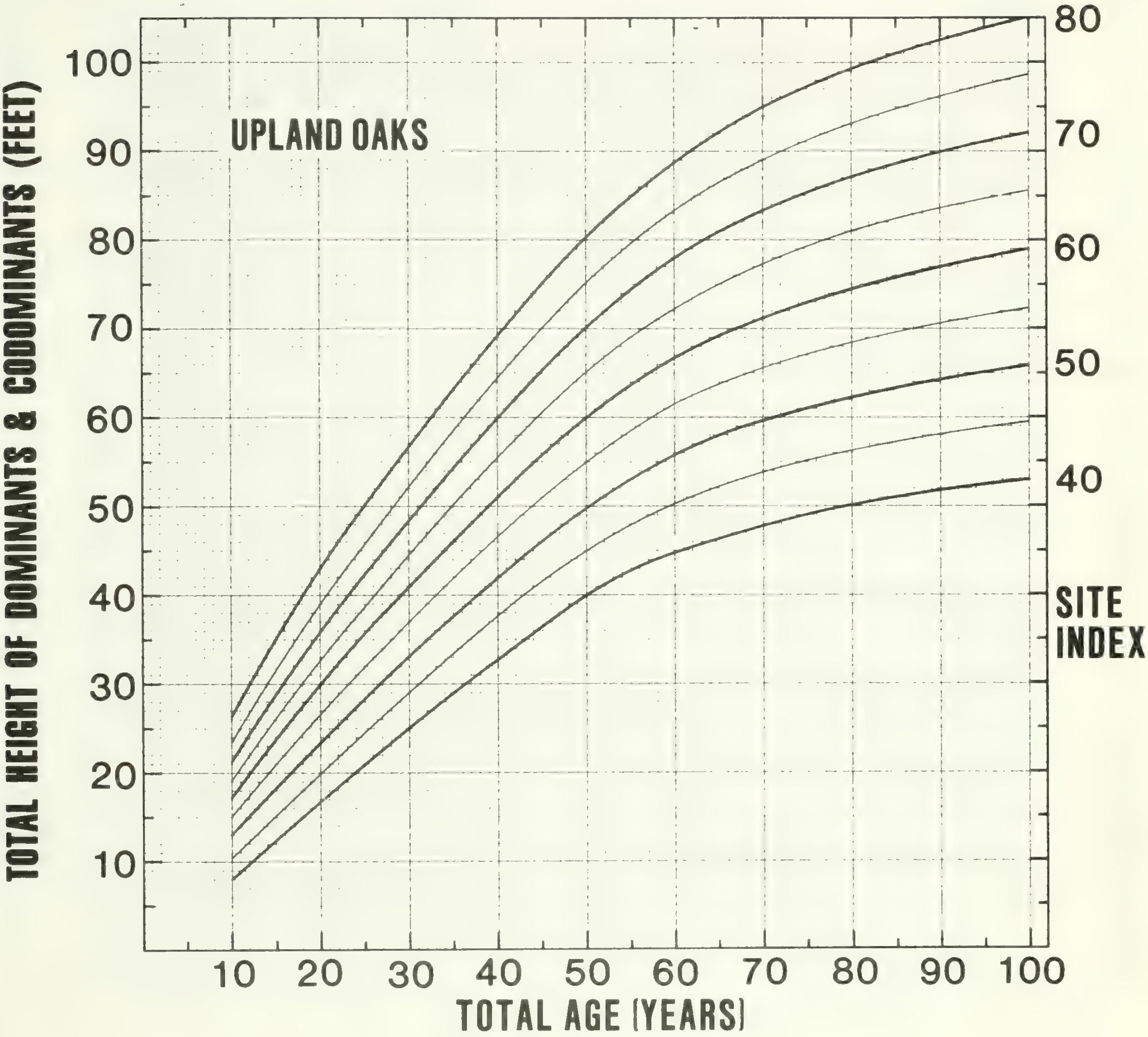

Figure 36.—Upland oaks (Schnur 1937)

Michigan south to Georgia, Missouri east to Pennsylvania and Maryland

404 plots, combined data for white, black, scarlet, chestnut, and red oaks; number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.99	1.67	6.6
SI	0.1890	1.2031	-0.0081	-2.1975	-0.2582	0.98	2.23	4.9

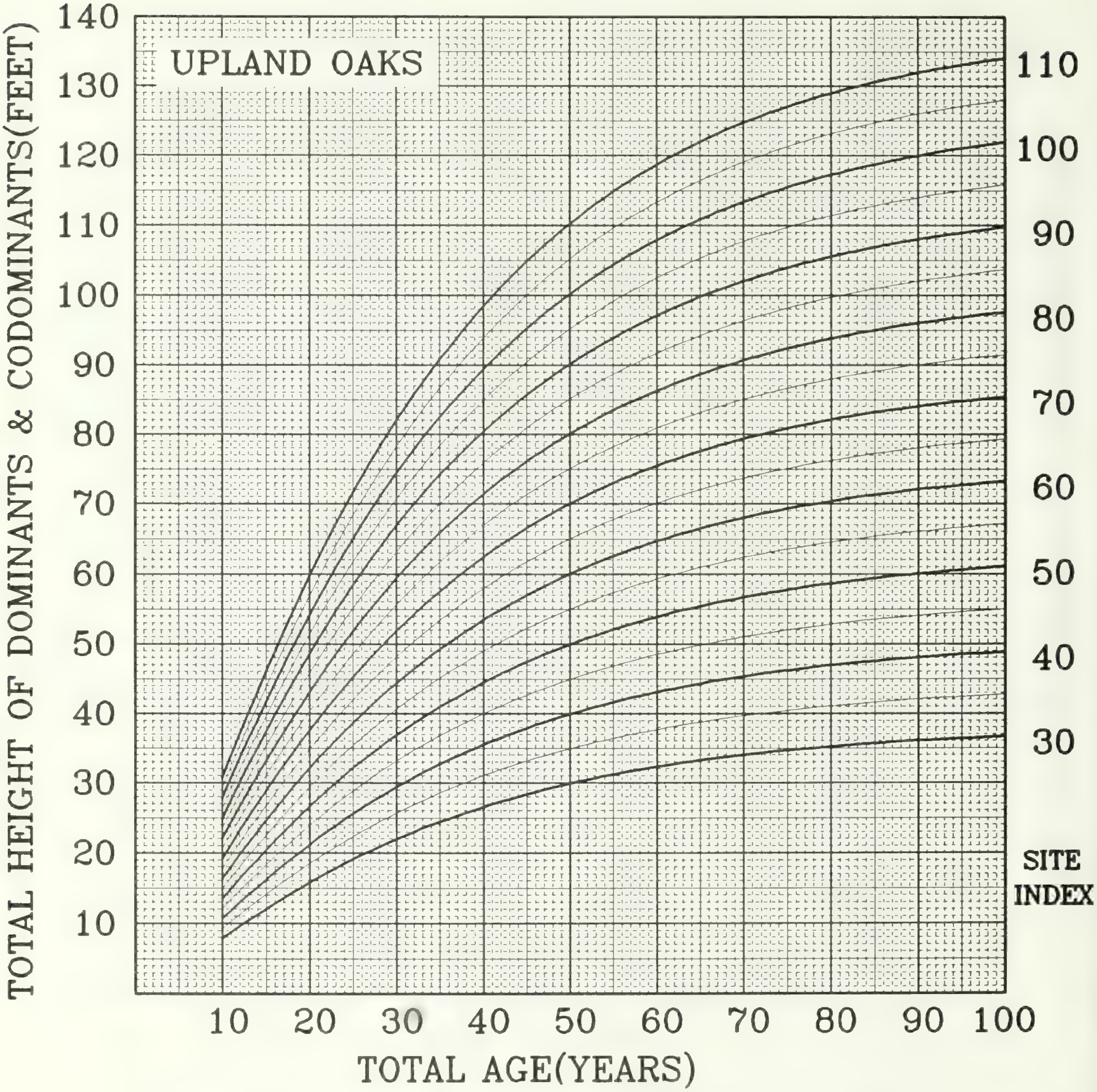

Figure 37.—Upland oaks (Olson 1959)

Virginia-Carolina Piedmont and northern Appalachian Mountains
269 plots in Piedmont, 428 plots in Appalachians, combined data for white, northern red, southern red, scarlet, black, and chestnut oaks; number of dominant and codominant trees not given
Total height and total age, logarithm equation, anamorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2866	0.9962	-0.0355	1.4485	-0.0316	0.99	1.22	3.0
SI	0.7709	1.0063	-0.0356	-1.5038	-0.0419	0.99	1.29	4.4

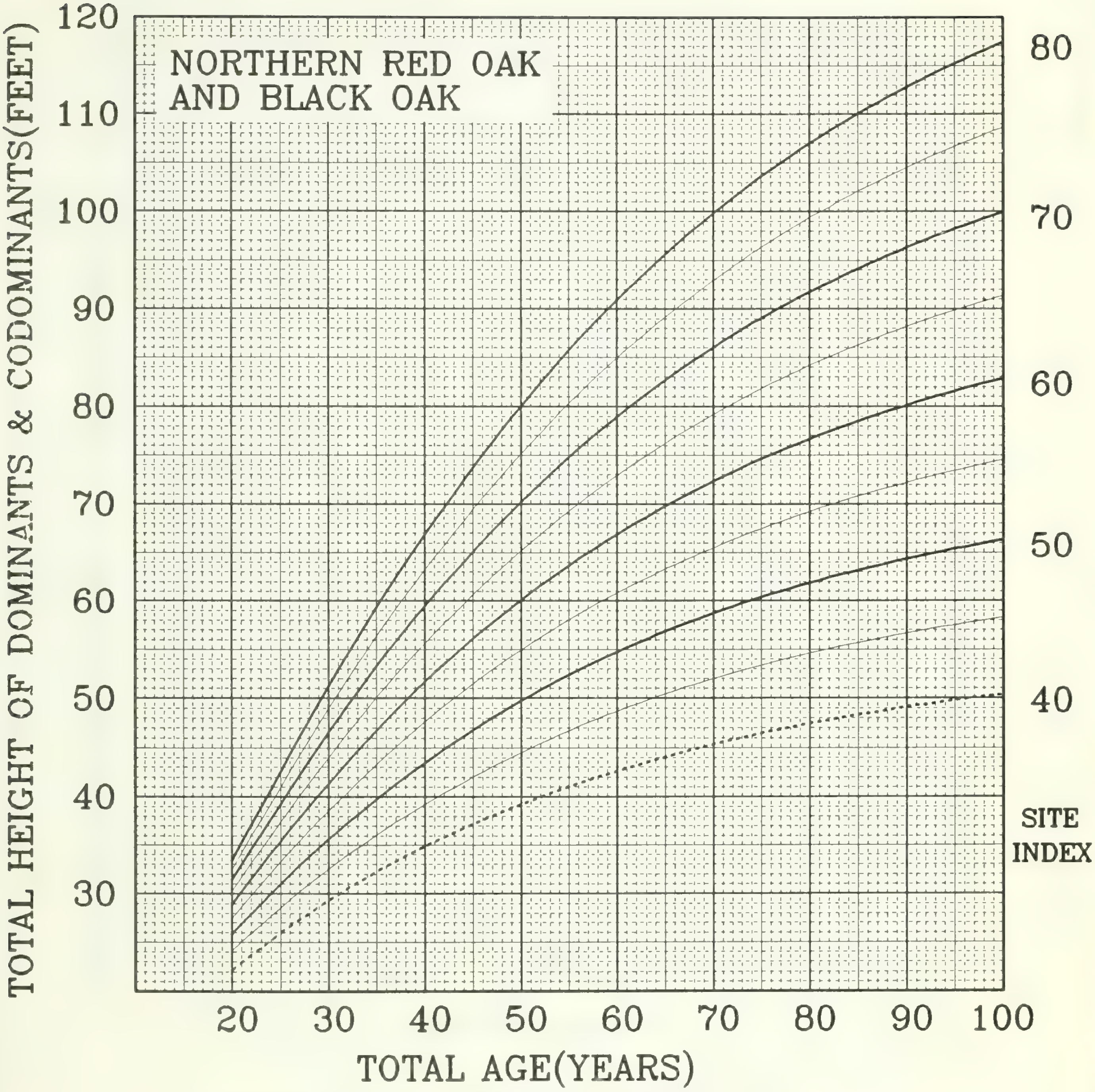

Figure 38.—Northern red oak and black oak (Graney and Bower 1971)
Boston Mountains of Arkansas
Number of plots not given, 142 dominant and codominant trees
Stem analysis, polynomial equation, anamorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.4737	1.2905	-0.0236	0.0979	0.6121	0.99	2.01	10.3
SI	1.6229	0.8134	-0.0439	-0.1886	0.6157	0.99	1.46	6.5

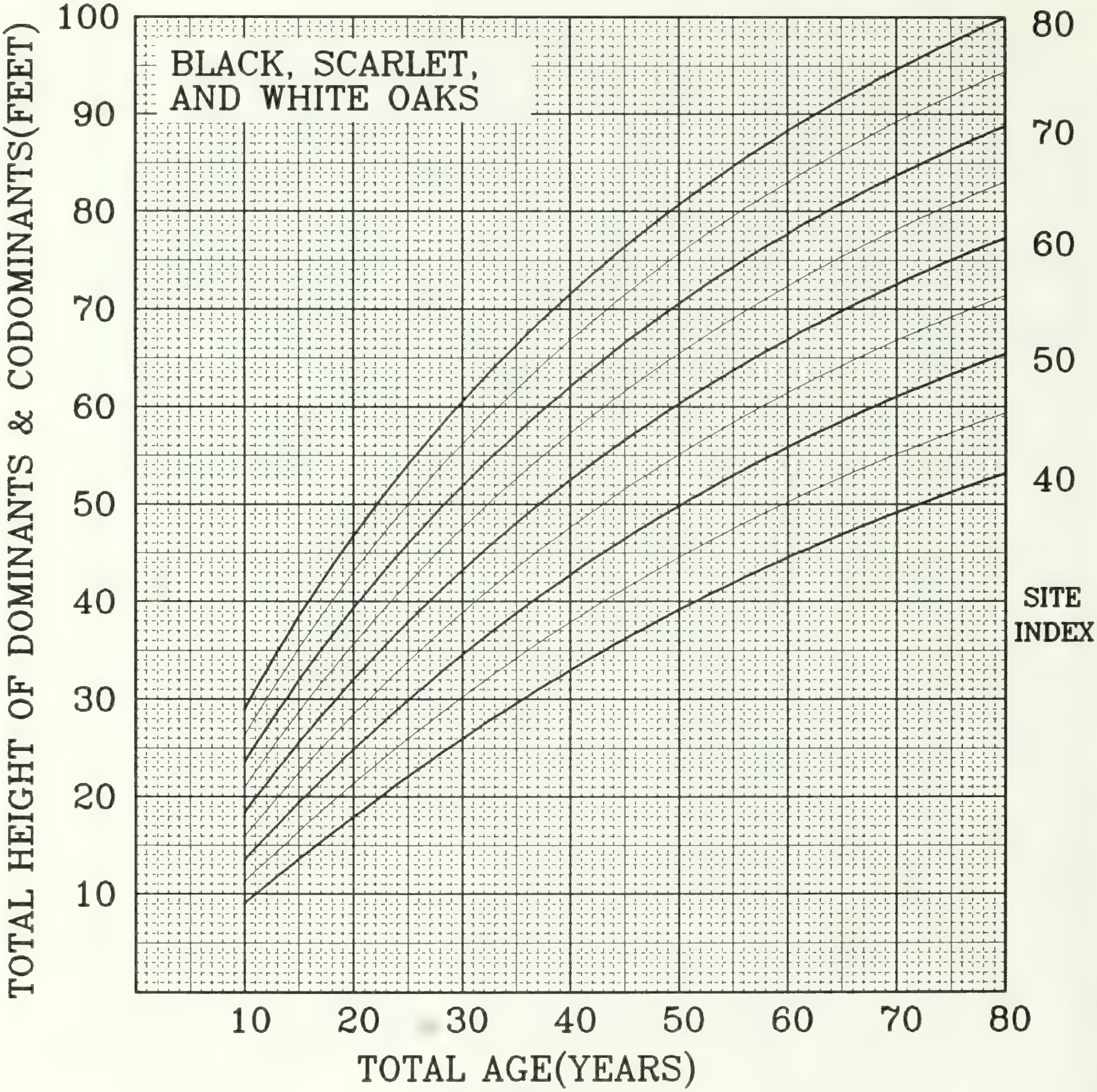

Figure 39.—Black, scarlet, and white oaks (McQuilkin 1974, 1978)
Missouri Ozarks—Clark and Mark Twain National Forests
Number of plots not given; combined data for 399 black oak, 276 white oak, and 66 scarlet oak dominant and codominant trees
Stem analysis, anamorphic, site index prediction equations using Hegar (1968) model, separate equations for black and scarlet oak, and for white oak (McQuilkin 1974)
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.9676	-0.7459	-0.0154	7.3640	-0.5144	0.99	1.92	3.5
SI	0.0064	1.6595	-0.0003	-1.8660	-0.2916	0.99	1.82	2.7

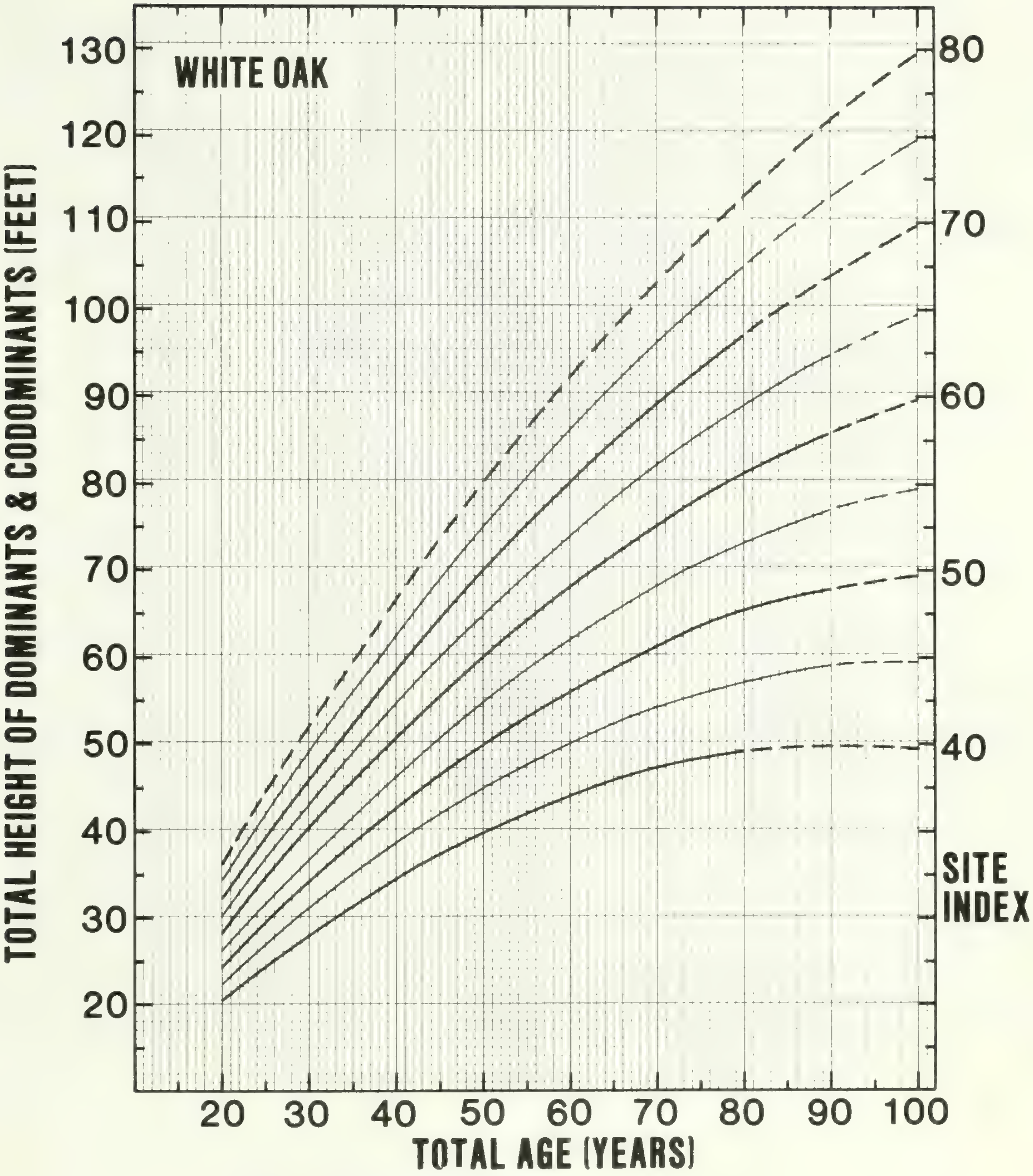

Figure 40.—White oak (Graney and Bower 1971)
Boston Mountains of Arkansas
Number of plots not given, 136 dominant and codominant trees
Stem analysis, polynomial equation, anamorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.5605	1.3105	-0.0145	0.1779	0.4323	0.99	1.17	6.2
SI	1.4040	0.8163	-0.0314	-0.3078	0.4260	0.99	0.98	3.4

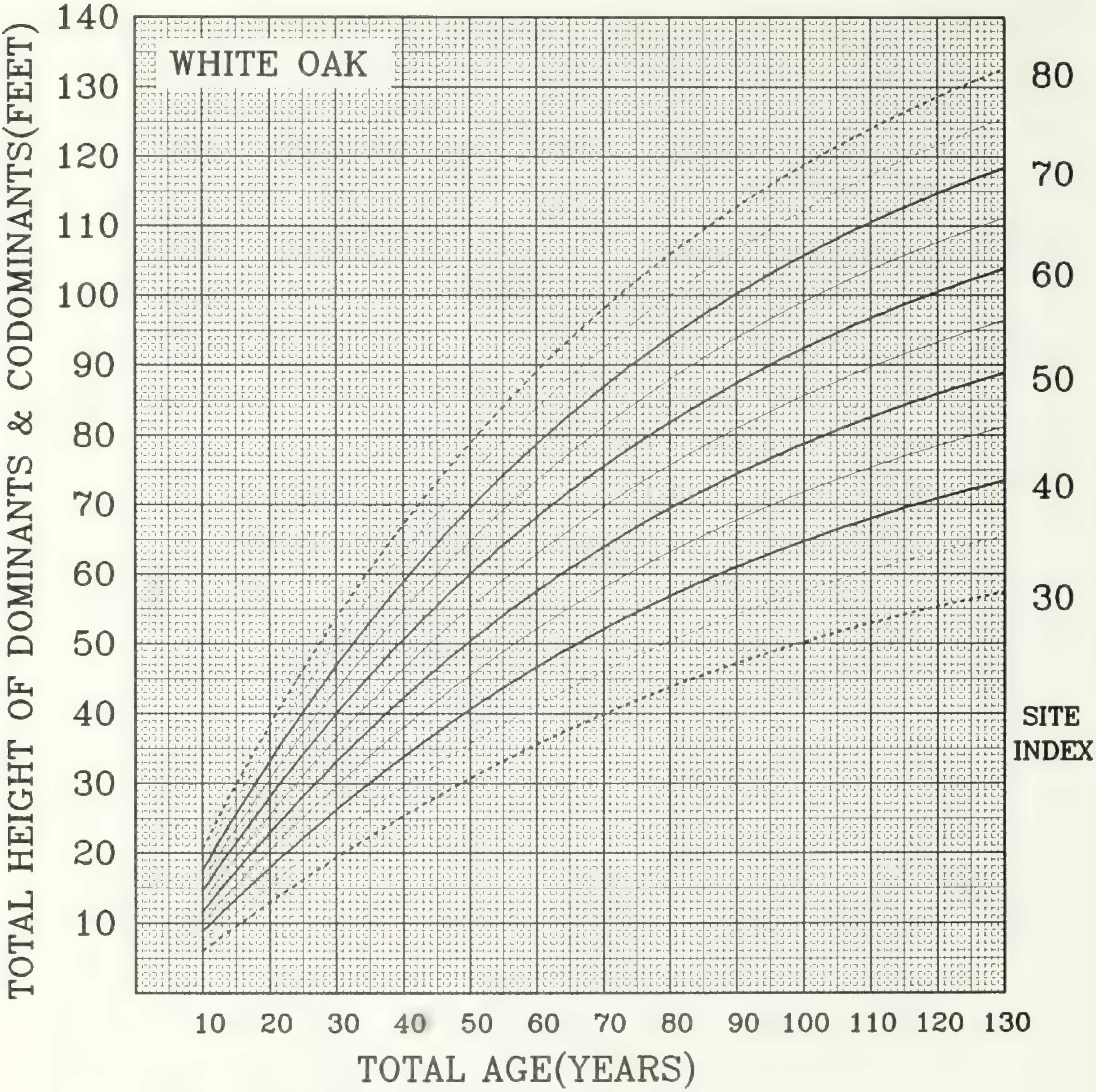

Figure 41.—White oak (Carmean 1971, 1972)

Unglaciated uplands of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri
41 plots having 112 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.5598	0.8136	-0.0132	2.2410	-0.1880	0.99	2.69	(1)
SI	0.3387	1.0135	-0.0076	-0.9644	-0.0176	0.99	2.90	(1)

(1) Value not calculated because model was fitted to original data rather than to site index curves.

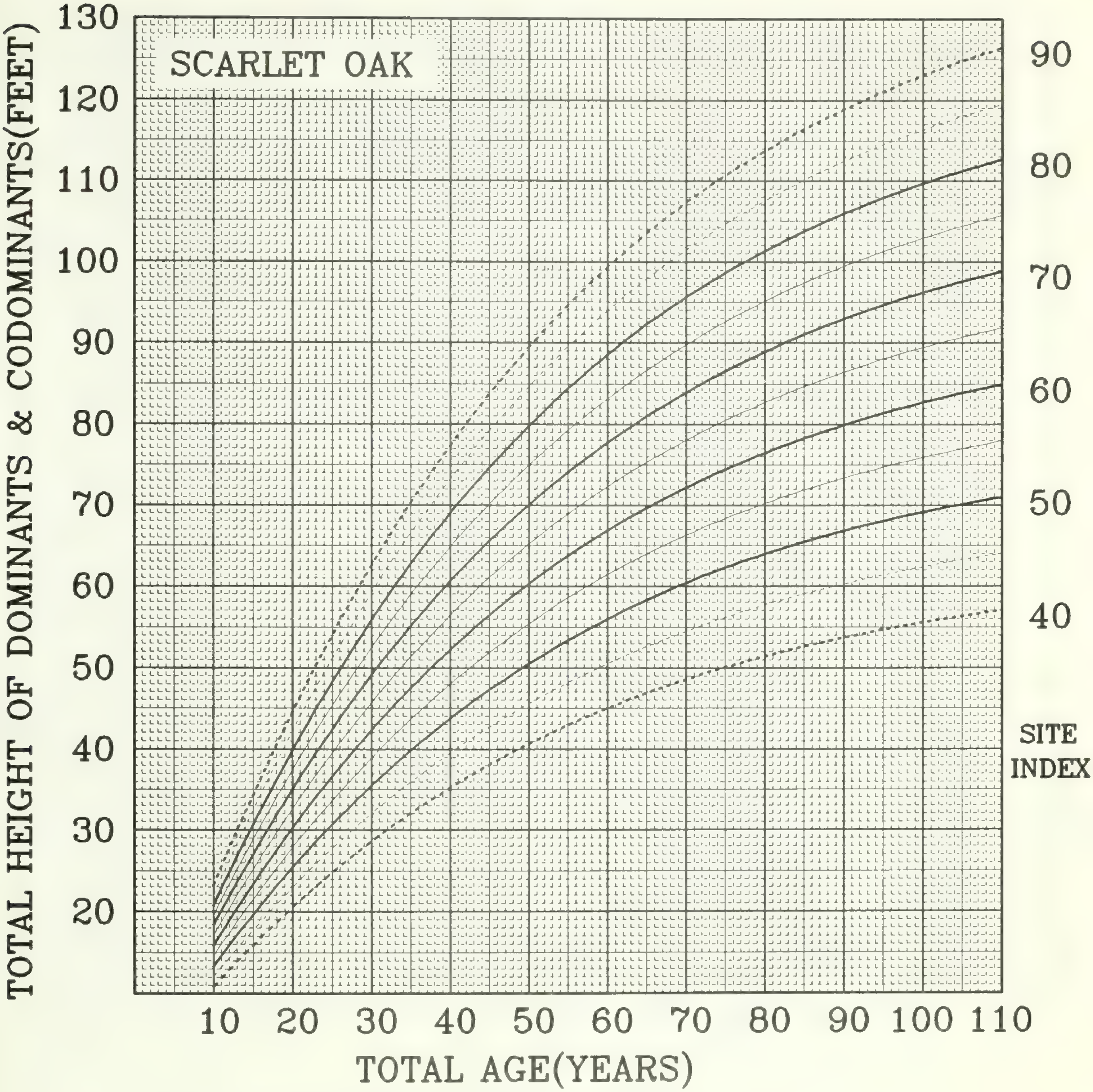

Figure 42.—Scarlet oak (Carmean 1971, 1972)
Unglaciated uplands of southeastern Ohio, eastern Kentucky, southern Illinois, and southern Missouri
25 plots having 88 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.6763	0.9837	-0.0220	0.9949	0.0240	0.99	2.77	(1)
SI	0.7423	0.9677	-0.0223	-1.0260	-0.0137	0.99	5.29	(1)

(1) Value not calculated because model was fitted to original data rather than to site index curves.

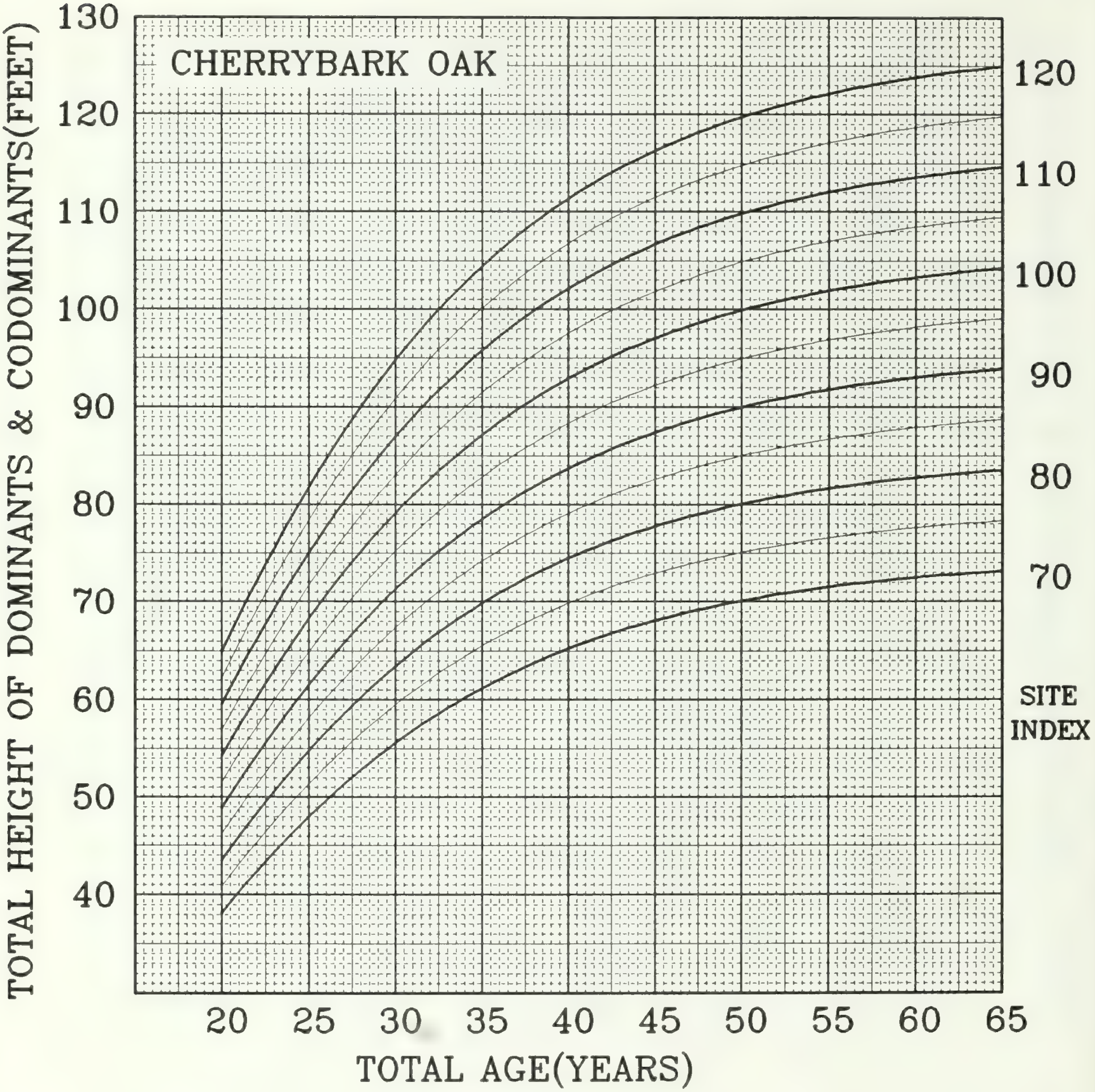

Figure 43.—Cherrybark oak (Broadfoot 1961)

Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee

Number of plots and number of dominant and codominant trees not given

Stem analysis, graphically constructed anamorphic curves

Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0945	0.9938	-0.0755	2.5601	0.0114	0.99	1.03	4.2
SI	0.9452	0.9987	-0.0762	-1.8868	0.0861	0.99	1.37	5.7

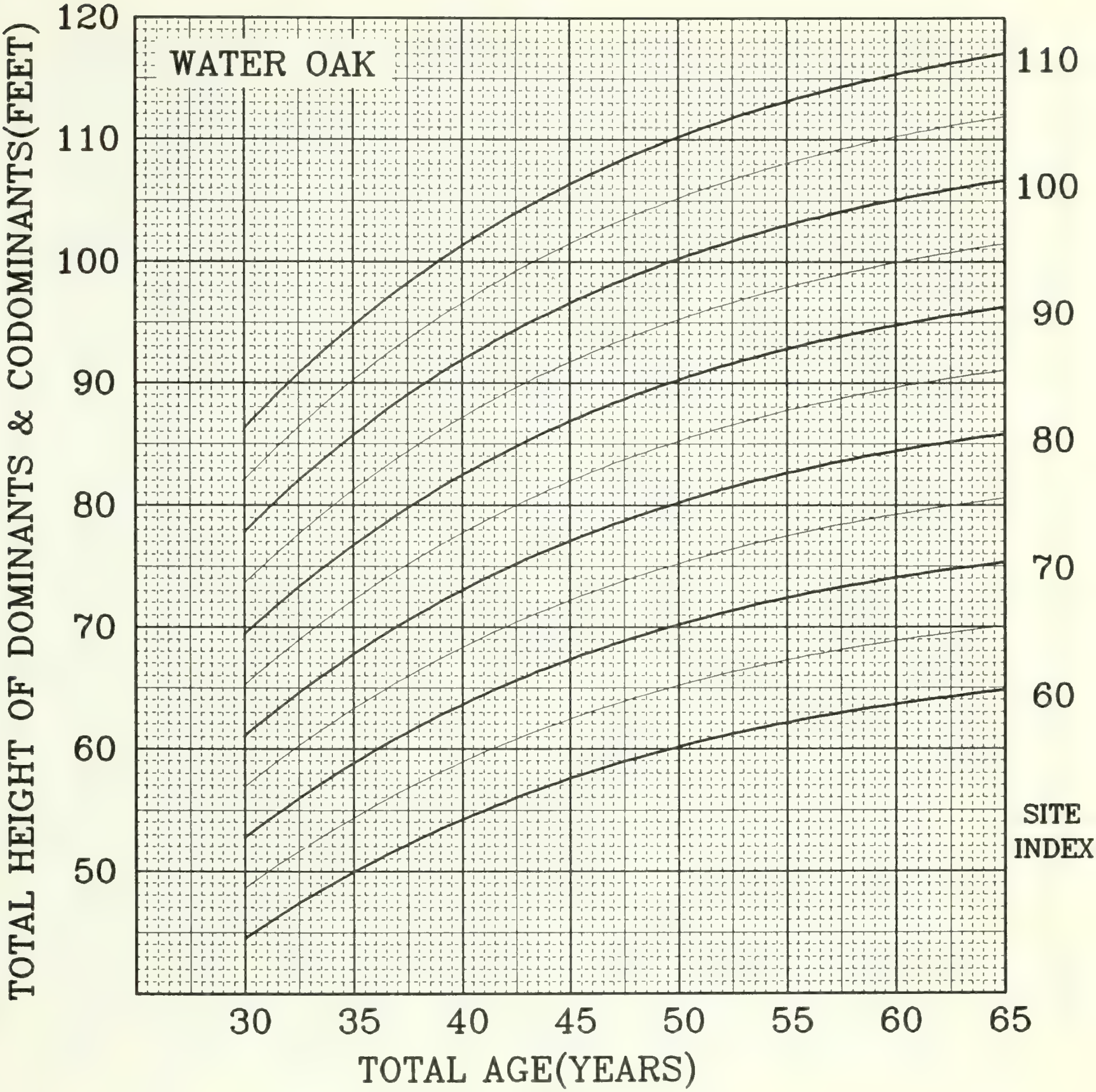

Figure 44.—Water oak (Broadfoot 1963)

Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee

Number of plots and number of dominant and codominant trees not given

Stem analysis, graphically constructed anamorphic curves

Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3466	0.9590	-0.0574	8.9538	-0.3454	0.99	0.62	2.2
SI	0.7317	1.0415	-0.0504	-6.1926	-0.3191	0.99	0.69	2.4

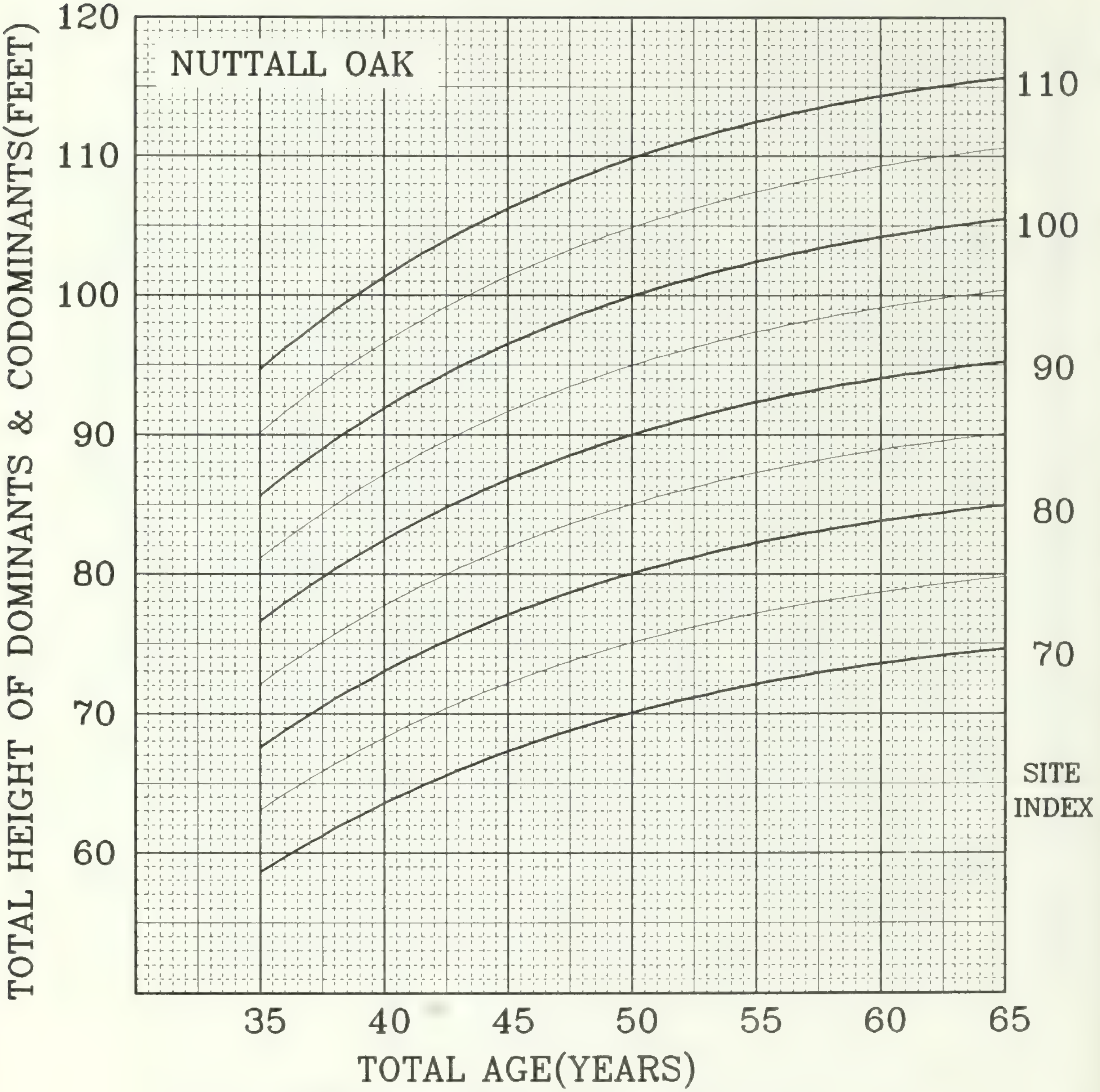

Figure 45.—Nuttall oak (Broadfoot 1969)
Mississippi Valley alluvium—Louisiana, Mississippi, Arkansas, Tennessee
Number of dominant and codominant trees not given
Stem analysis, graphically constructed anamorphic curves
Add 2 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3295	0.9565	-0.0668	16.0085	-0.4157	0.99	0.38	1.9
SI	0.7488	1.0424	-0.0597	-10.0941	-0.3709	0.99	0.42	2.1

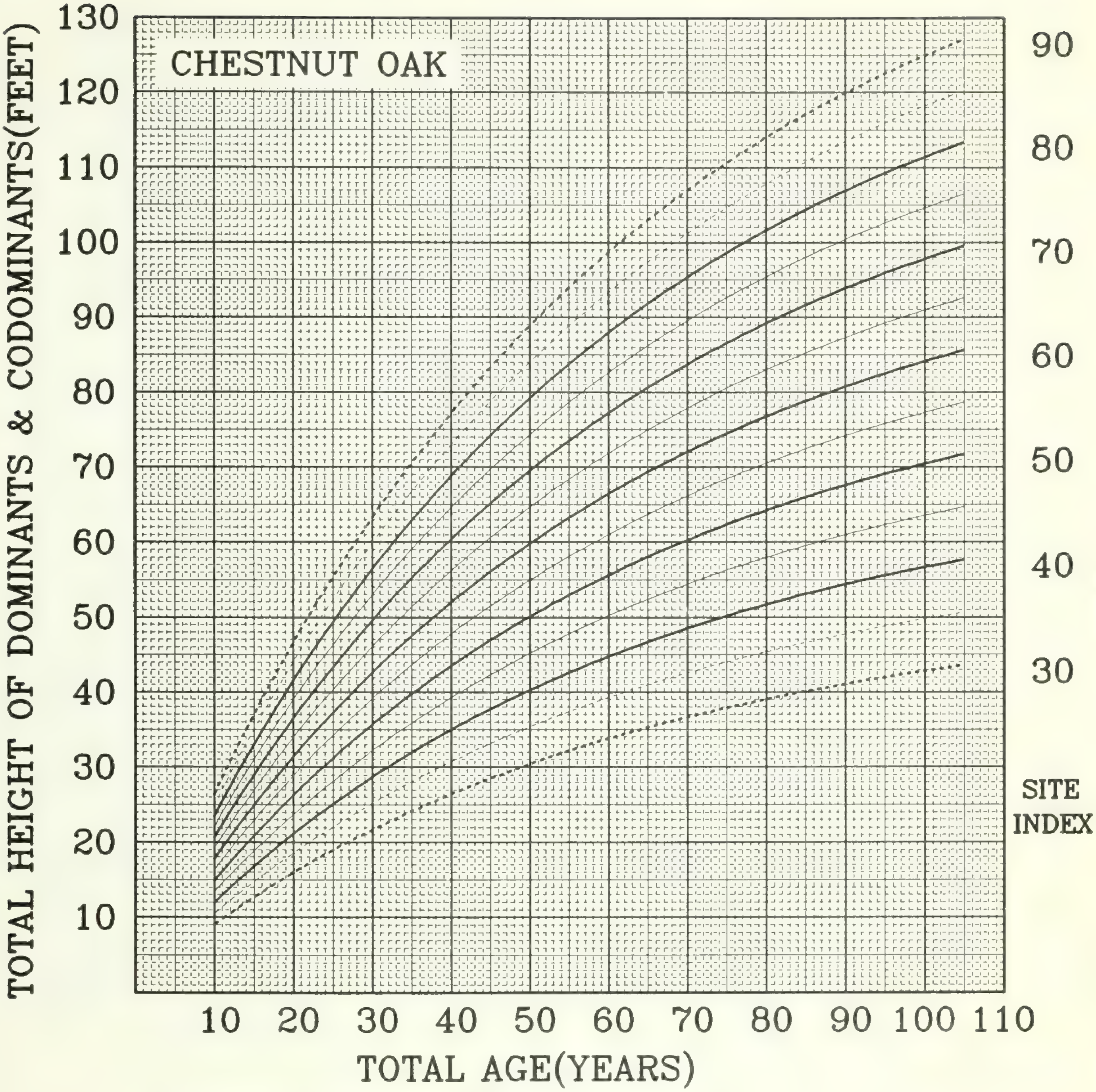

Figure 46.—Chestnut oak (Carmean 1971, 1972)
Unglaciated uplands of southeastern Ohio, eastern Kentucky, and southern Indiana
18 plots having 59 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.9044	0.9752	-0.0162	0.9262	0.0000	0.99	3.28	(1)
SI	0.4124	1.0394	-0.0100	-0.9980	-0.0583	0.99	6.85	(1)

(1) Value not calculated because model was fitted to original data rather than to site index curves.

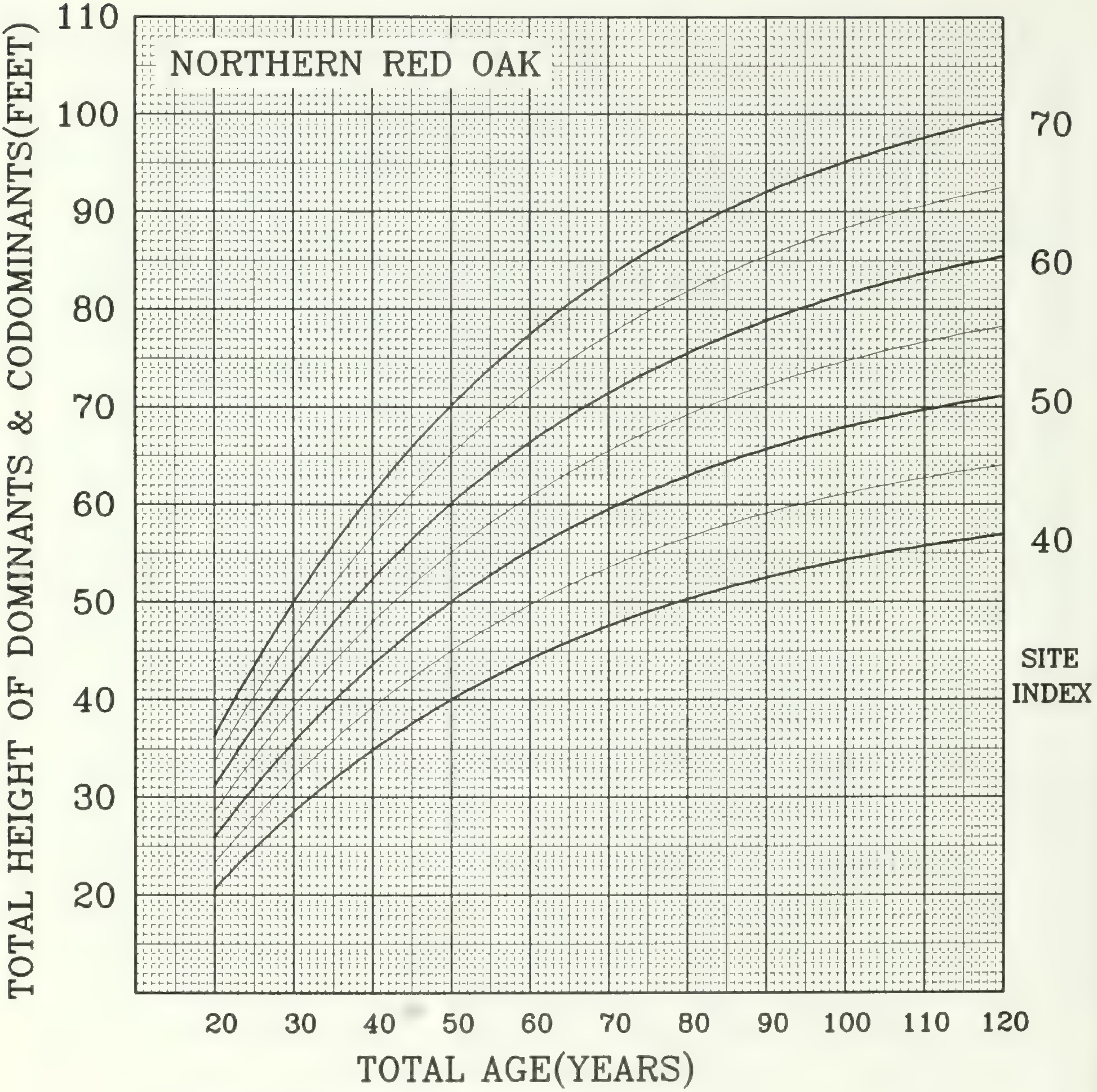

Figure 47.—Northern red oak (Gevorkiantz 1957b)
Southwestern Wisconsin
Number of plots and number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5403	1.0006	-0.0216	1.0616	-0.0044	0.99	0.86	0.7
SI	1.0000	0.9058	-0.0269	-0.5382	0.2108	0.98	1.19	3.4

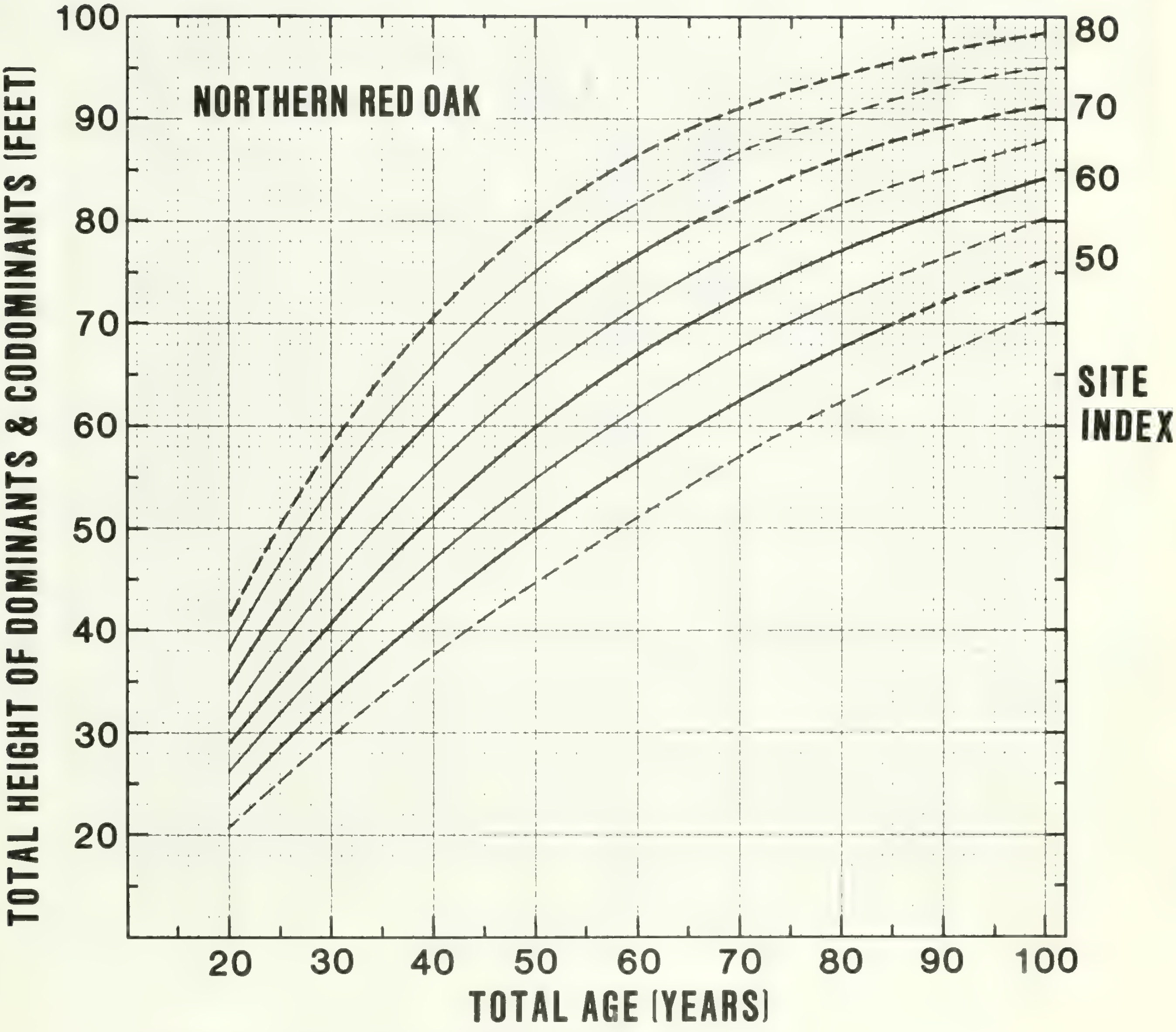

Figure 48.—Northern red oak (Carmean 1978)
Northern Wisconsin and Upper Michigan
37 plots having 136 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.1785	0.6619	-0.0241	25.0185	-0.7400	0.99	1.32	4.9
SI	0.1692	1.2648	-0.0110	-3.4334	-0.3557	0.97	2.09	7.8

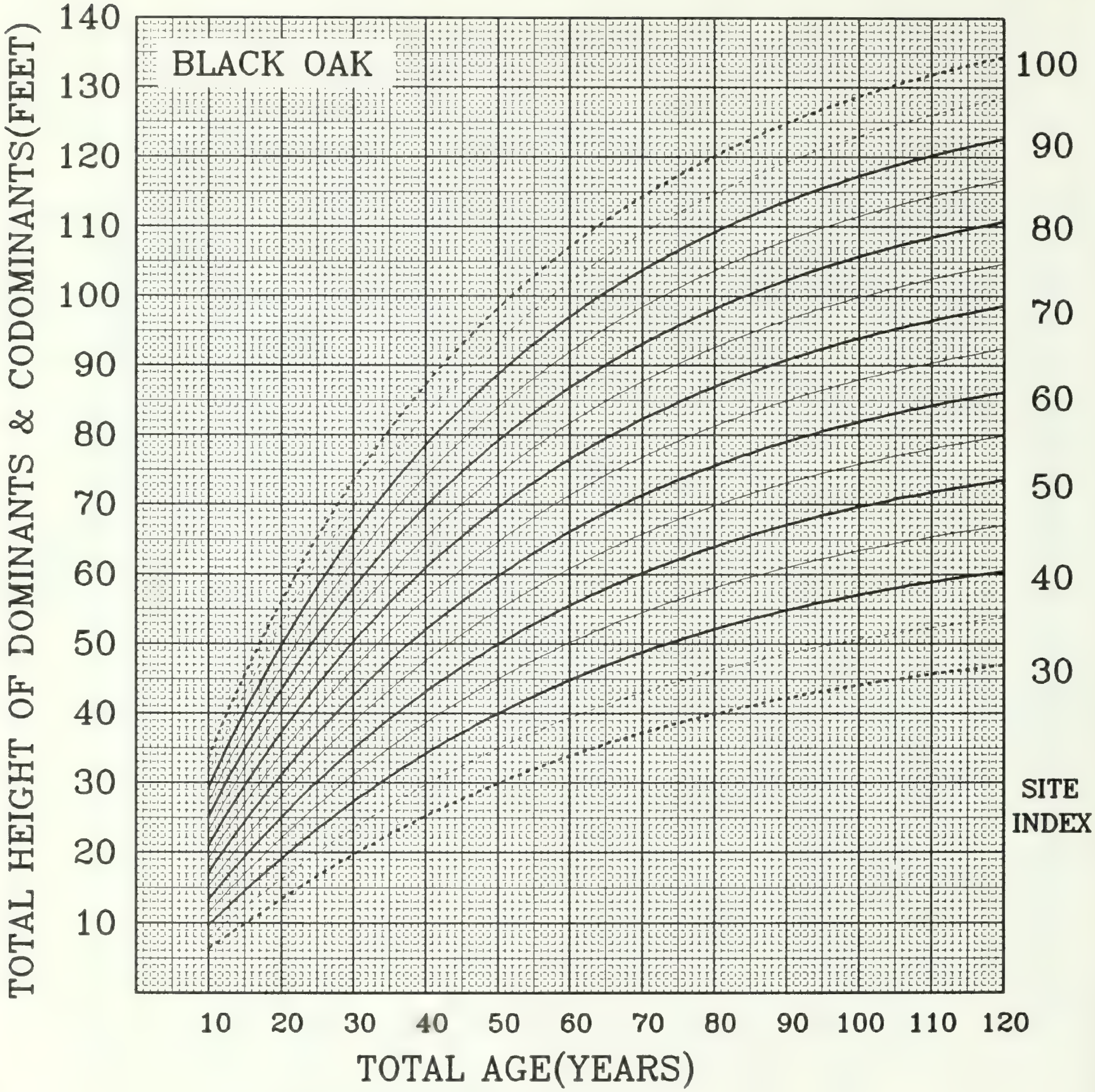

Figure 49.—Black oak (Carmean 1971, 1972)
Unglaciated uplands of southeastern Ohio, eastern Kentucky, southern Indiana, and southern Missouri
120 plots having 300 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.9989	0.8435	-0.0200	3.4635	-0.3020	0.99	4.09	(1)
SI	0.2598	1.1721	-0.0107	-2.3272	-0.2825	0.99	4.42	(1)

(1) Value not calculated because model was fitted to original data rather than to site index curves.

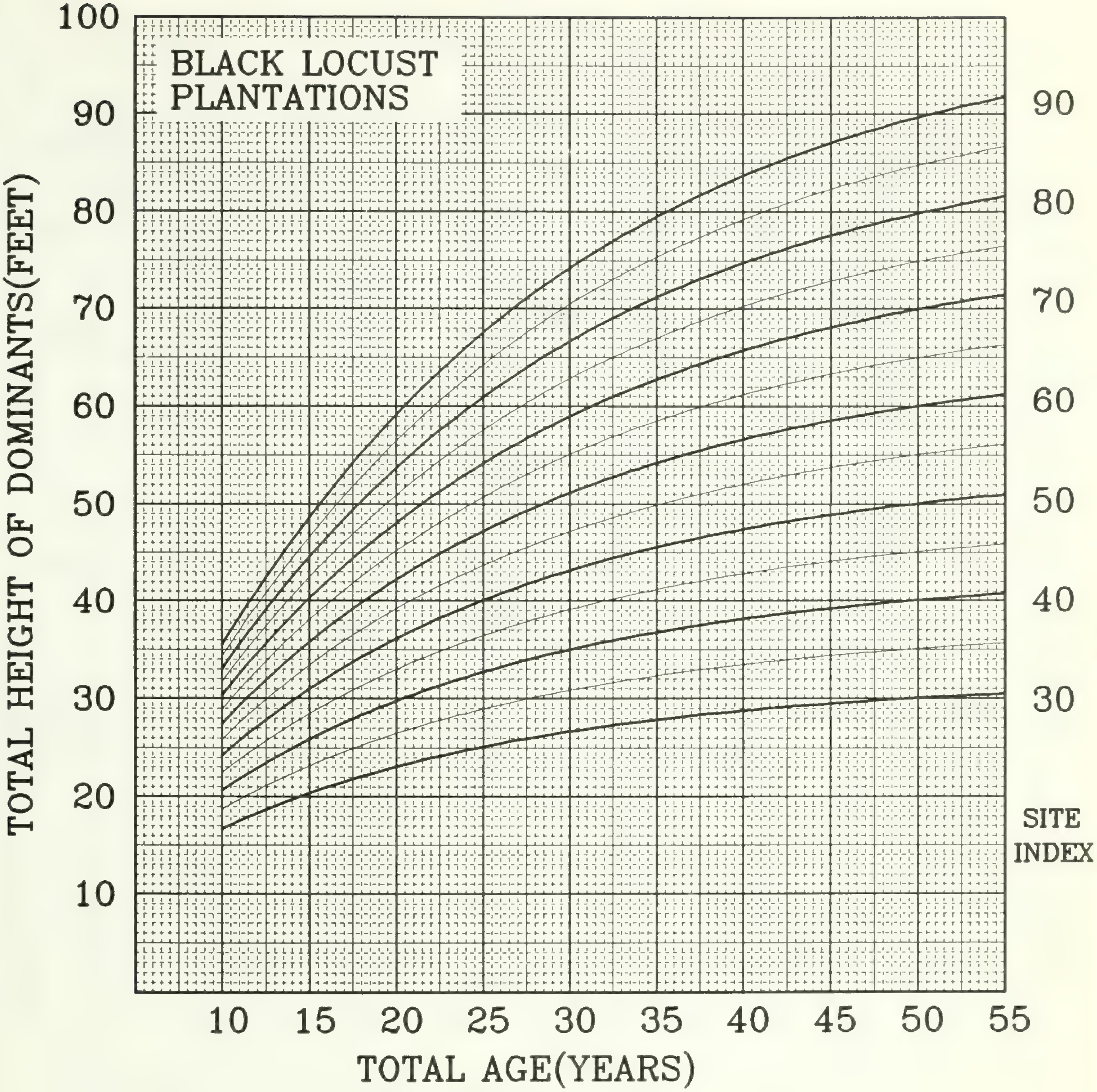

Figure 50.—Black locust plantations (Kellogg 1939a)
Central States
170 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30-45	46-65	66+
Years:	3	2	1

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.9680	1.0301	-0.0468	0.1639	0.4127	0.99	1.42	6.0
SI	0.9411	0.9941	-0.0535	-0.4600	0.2242	0.99	1.85	8.7

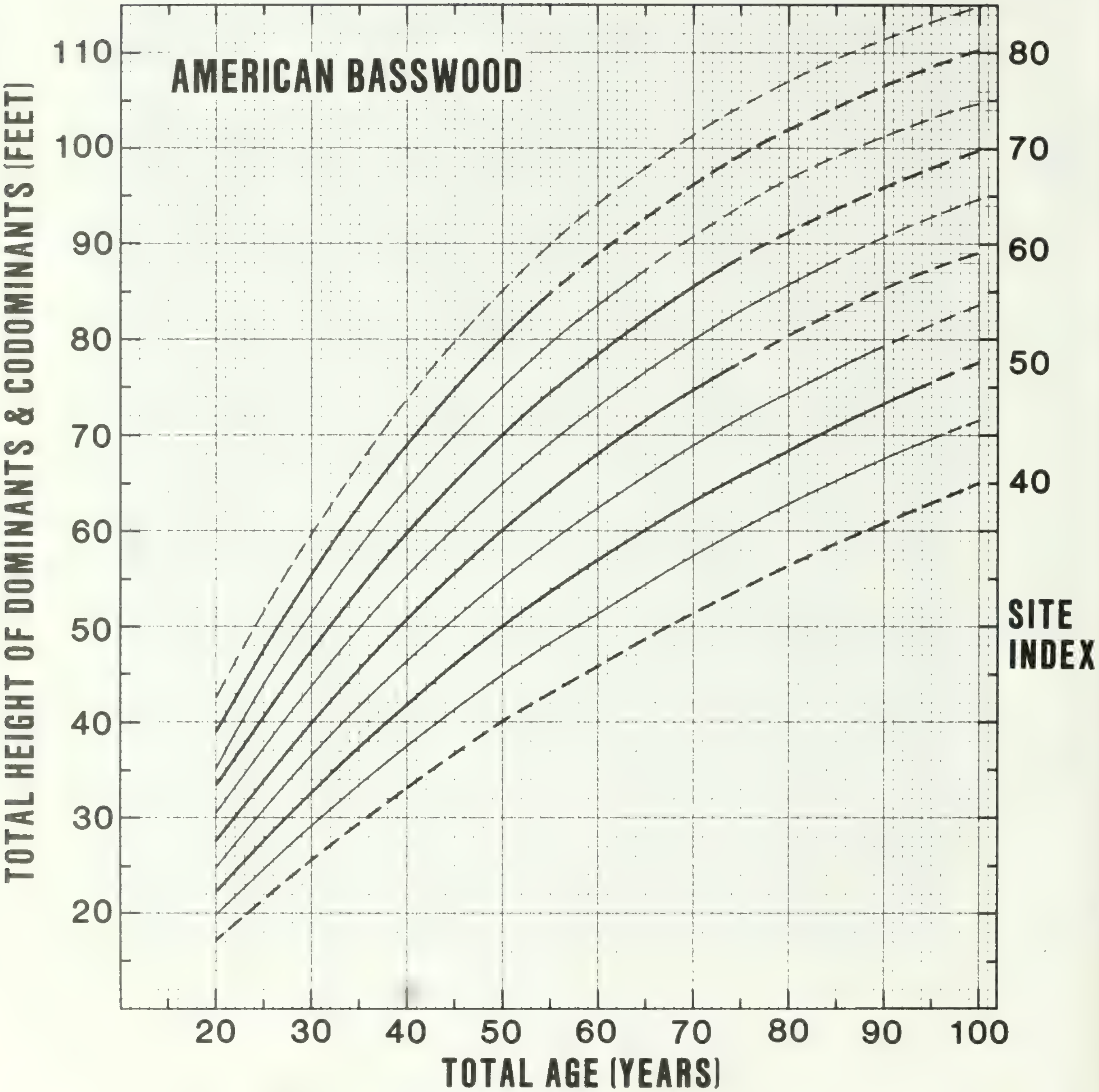

Figure 51.—American basswood (Carmean 1978)
Northern Wisconsin and Upper Michigan
122 plots having 483 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.7633	0.7576	-0.0194	6.5110	-0.4156	0.99	0.70	2.7
SI	0.1921	1.2010	-0.0100	-2.3009	-0.2331	0.99	1.24	4.5

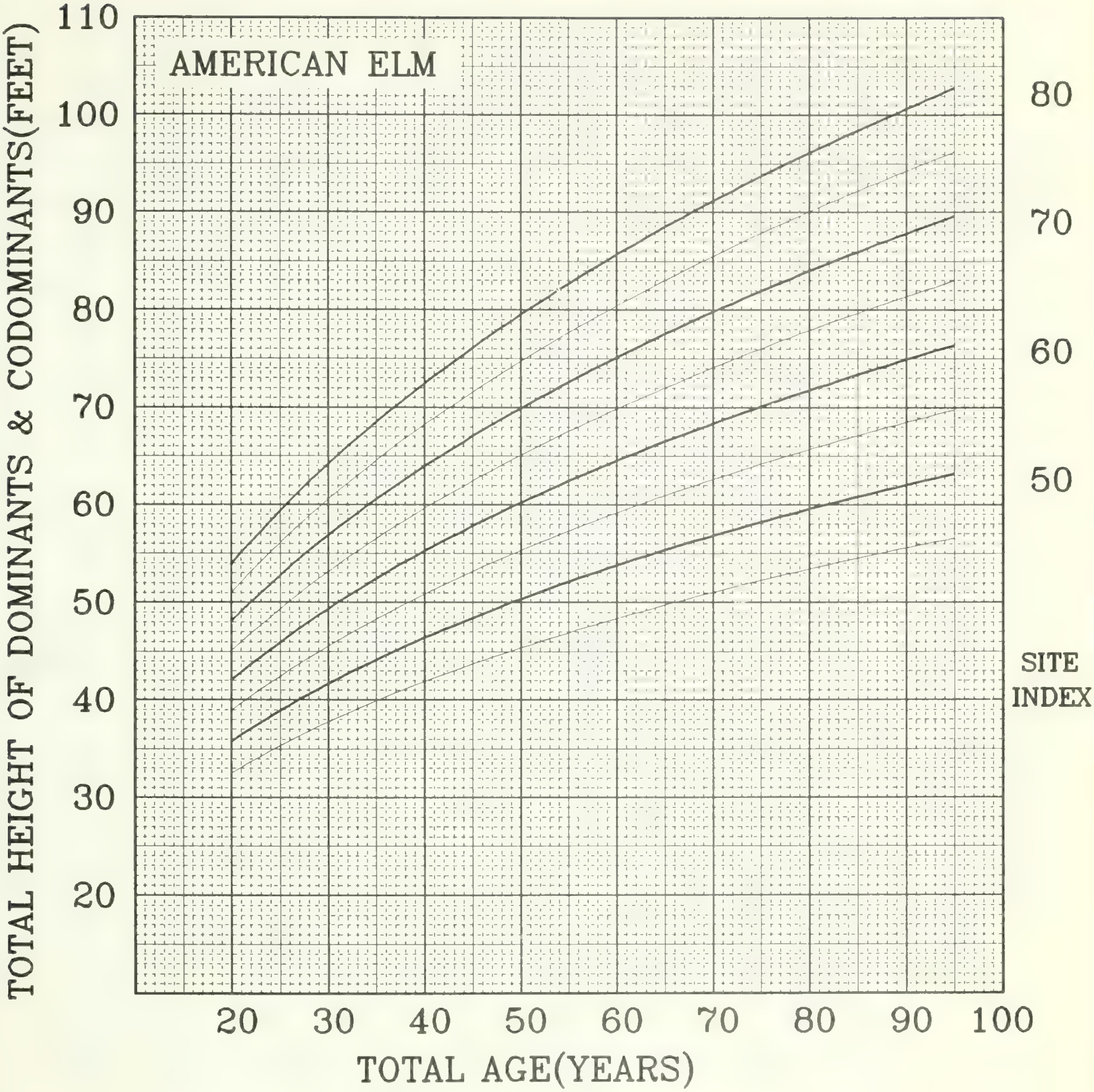

Figure 52.—American elm (Brendemuehl, McComb, and Thomson 1961a)
Southern Iowa
Number of plots and number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0370	1.1906	-0.0030	0.1391	0.2655	0.99	0.92	2.5
SI	1.1330	0.8807	-0.0160	-0.1140	-0.4054	0.99	1.22	4.1

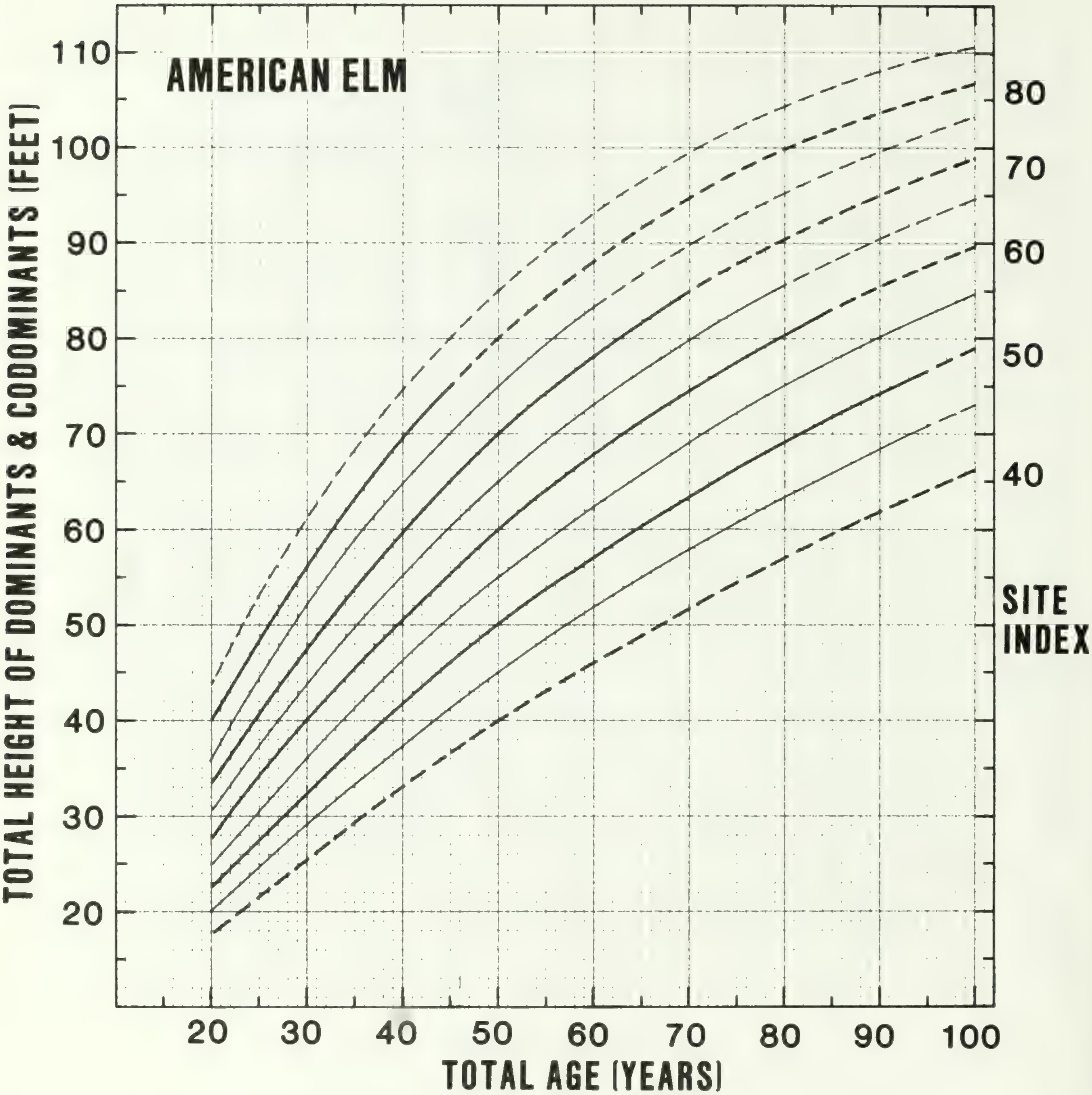

Figure 53.—American elm (Carmean 1978)
Northern Wisconsin and Upper Michigan
109 plots having 416 dominant and codominant trees
Stem analysis, nonlinear regression, polymorphic
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.99	1.12	4.4
SI	0.1898	1.2186	-0.0110	-2.6865	-0.2717	0.99	1.99	6.6

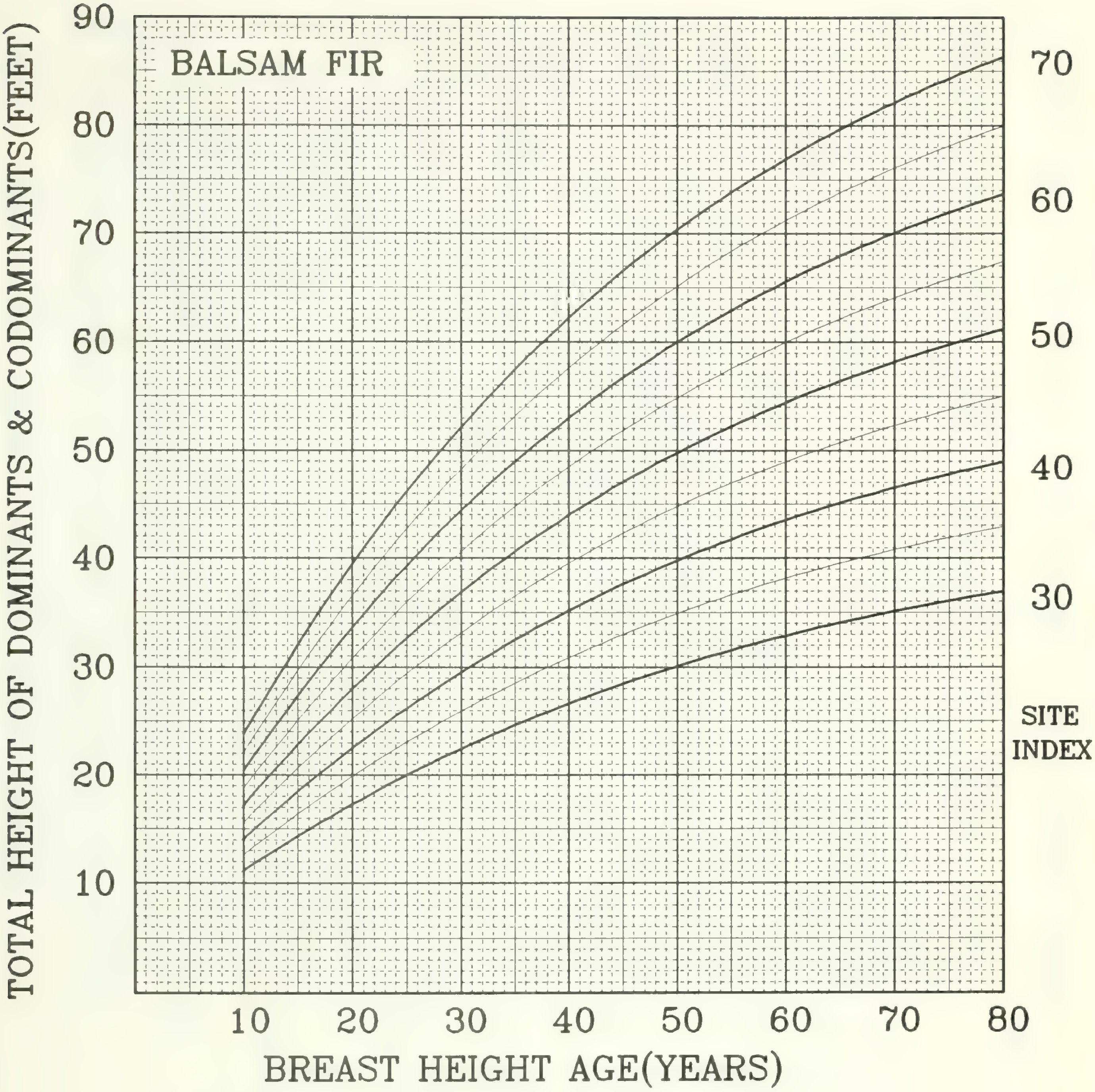

Figure 54.—Balsam fir (Gevorkiantz 1956b)
Lake States
Number of plots and number of dominant and codominant trees not given
Total height and breast height age, anamorphic, equation not given
Site index is total height of dominant and codominant trees at 50 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0438	1.0708	-0.0222	1.5915	-0.1068	0.99	1.08	1.6
SI	0.4358	1.0650	-0.0179	-0.7497	0.0251	0.99	1.18	2.1

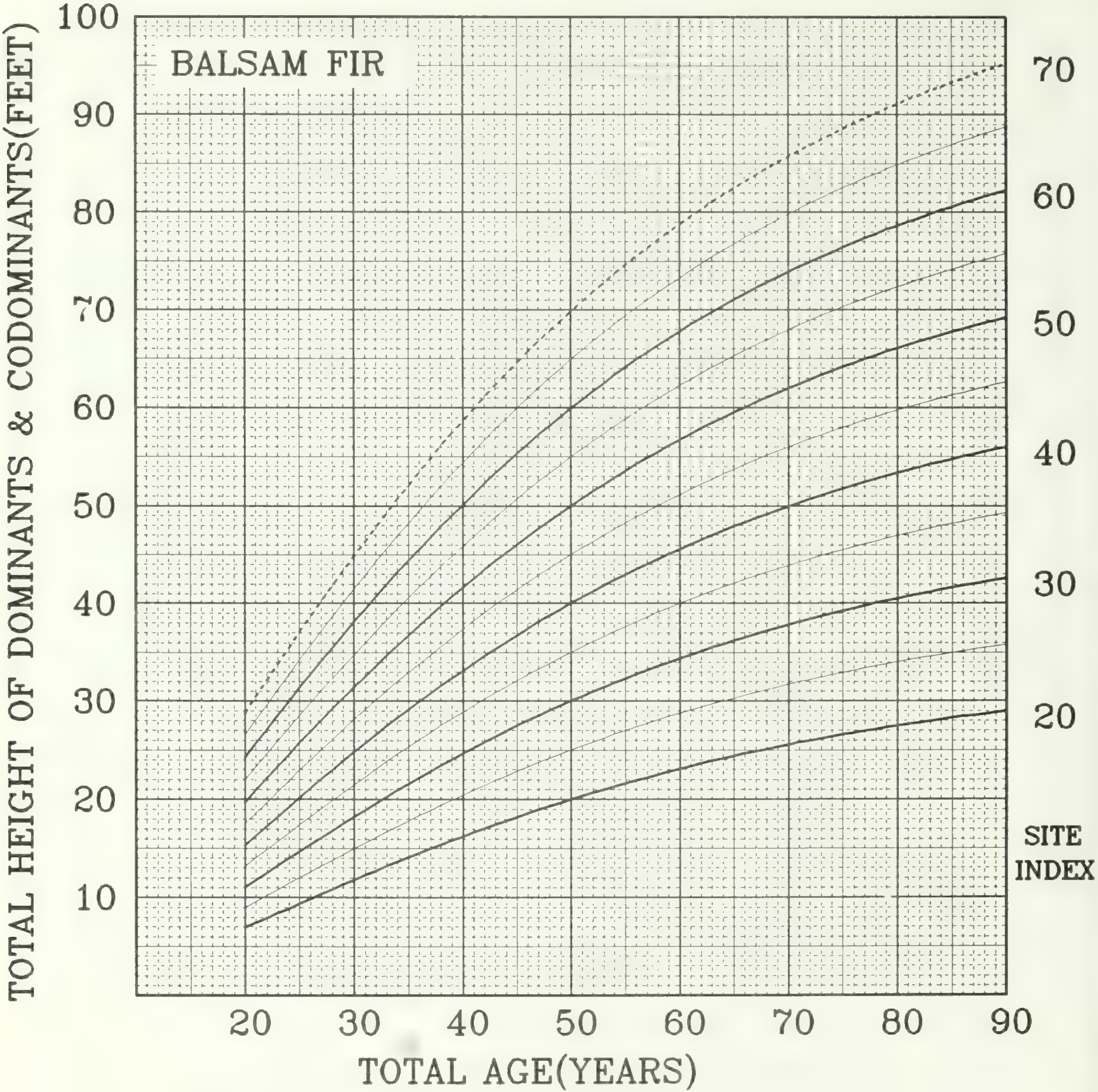

Figure 55.—Balsam fir (Carmean and Hahn 1981, revision of Gevorkiantz 1956b)

Lake States

Number of plots and number of dominant and codominant trees not given

Total height and total age, anamorphic, Gevorkiantz (1956b) equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60	70
Years:	15	13	11	10	9	8

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0770	0.9303	-0.0285	2.8937	-0.1414	0.97	0.95	1.7
SI	0.4100	1.0799	-0.0205	-2.1577	-0.1295	0.98	1.07	2.5

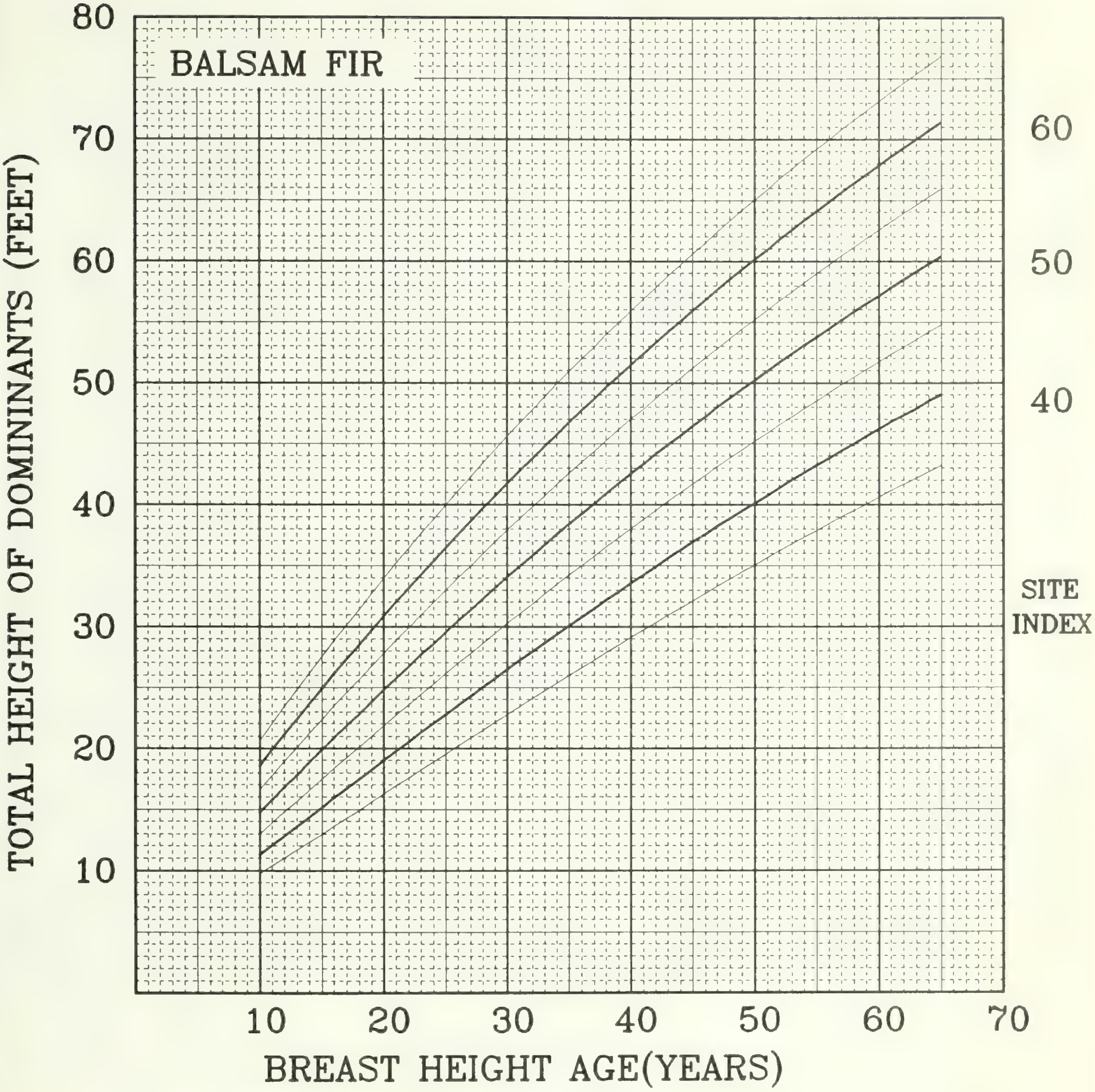

Figure 56.—Balsam fir (Griffin and Johnson 1980)
Northern Maine (Aroostock and Piscataquis Counties)
42 plots using stem analysis of "six tallest trees" (dominants) on each plot; trees older than 45 years breast height age
Stem analysis, quadratic regression, polymorphic
Site index is height of dominant trees at 50 years breast height age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	8.1200	0.6748	-0.0111	6.4229	-0.4586	0.99	0.95	1.1
SI	0.0061	1.3539	-0.00019	-1.0286	-0.0723	0.99	1.61	8.2

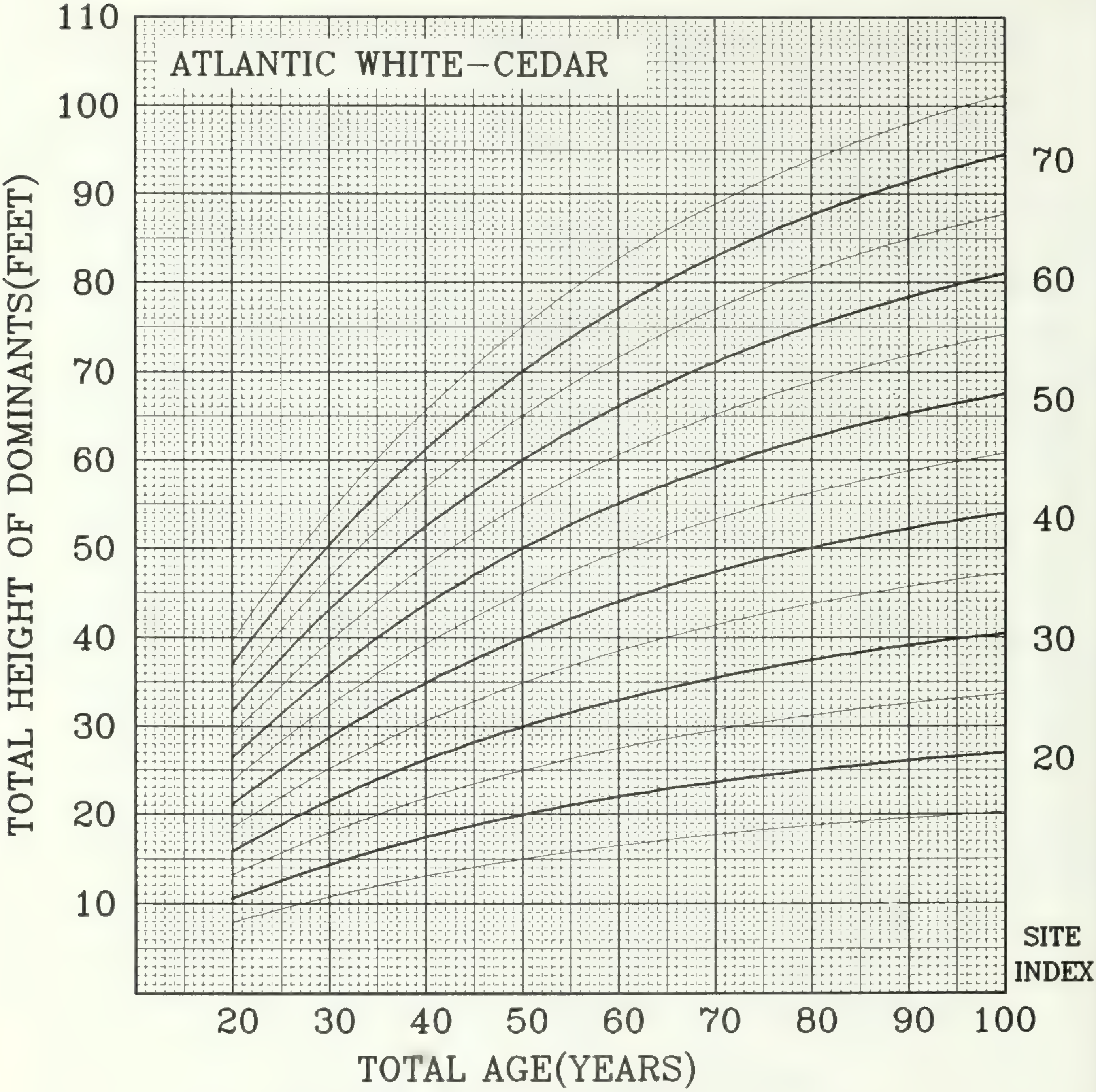

Figure 57.—Atlantic white-cedar (Korstian and Brush 1931)
Florida to Massachusetts
63 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60	70	80
Years:	11	10	9	8	7	6	5

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5341	1.0013	-0.0208	0.9986	-0.0012	0.99	0.18	1.0
SI	0.6528	1.0000	-0.0213	-1.0243	-0.0046	0.99	0.23	1.1

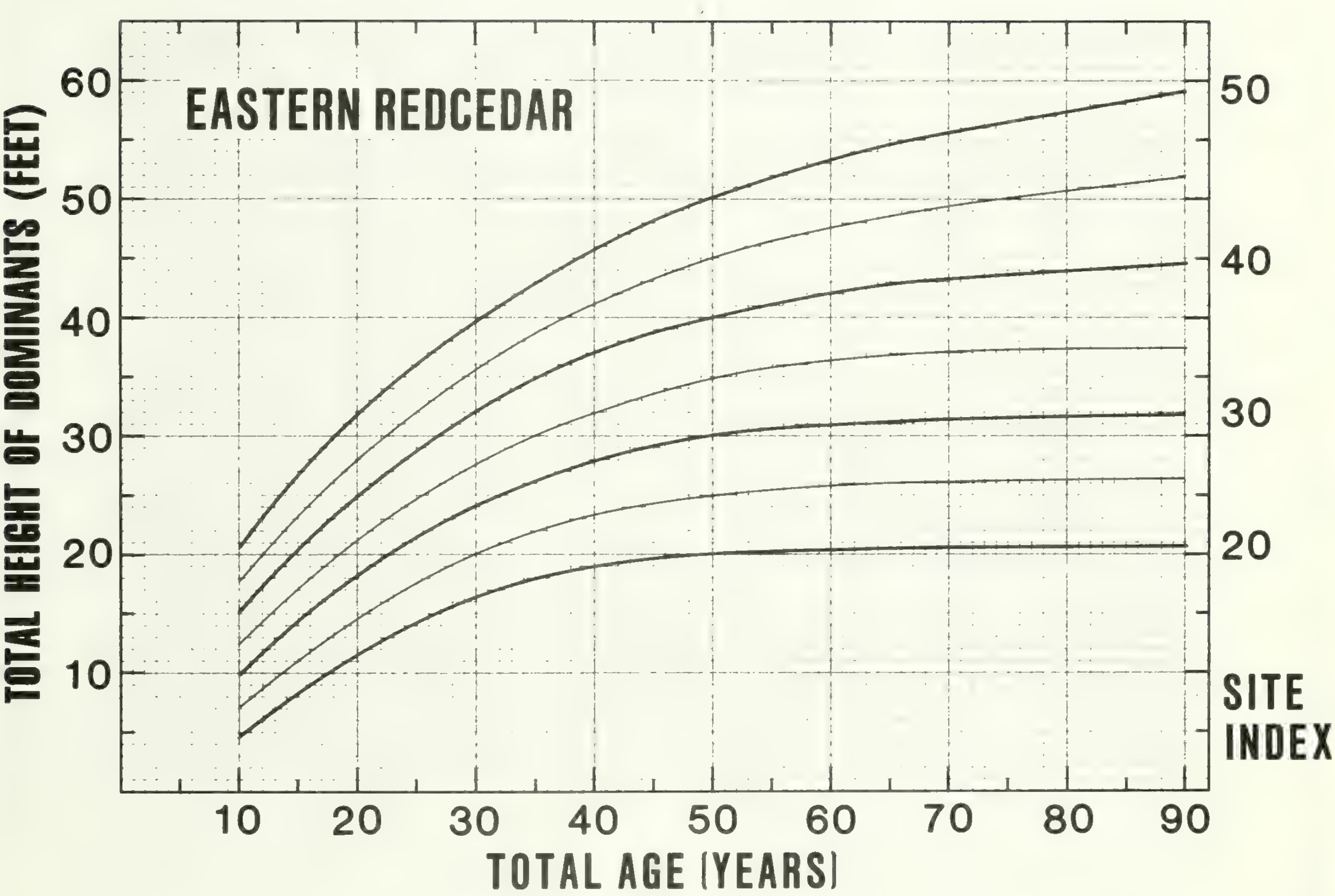

Figure 58.—Eastern redcedar (Hampf 1965)
Tennessee Valley
"Based on 271 observations"
Total height and total age of dominants, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60
Years:	14	12	11	10	9

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.9276	1.0591	-0.0424	0.3529	0.3114	0.99	1.10	4.1
SI	0.8965	0.9895	-0.0397	-1.0981	-0.0242	0.99	1.41	7.0

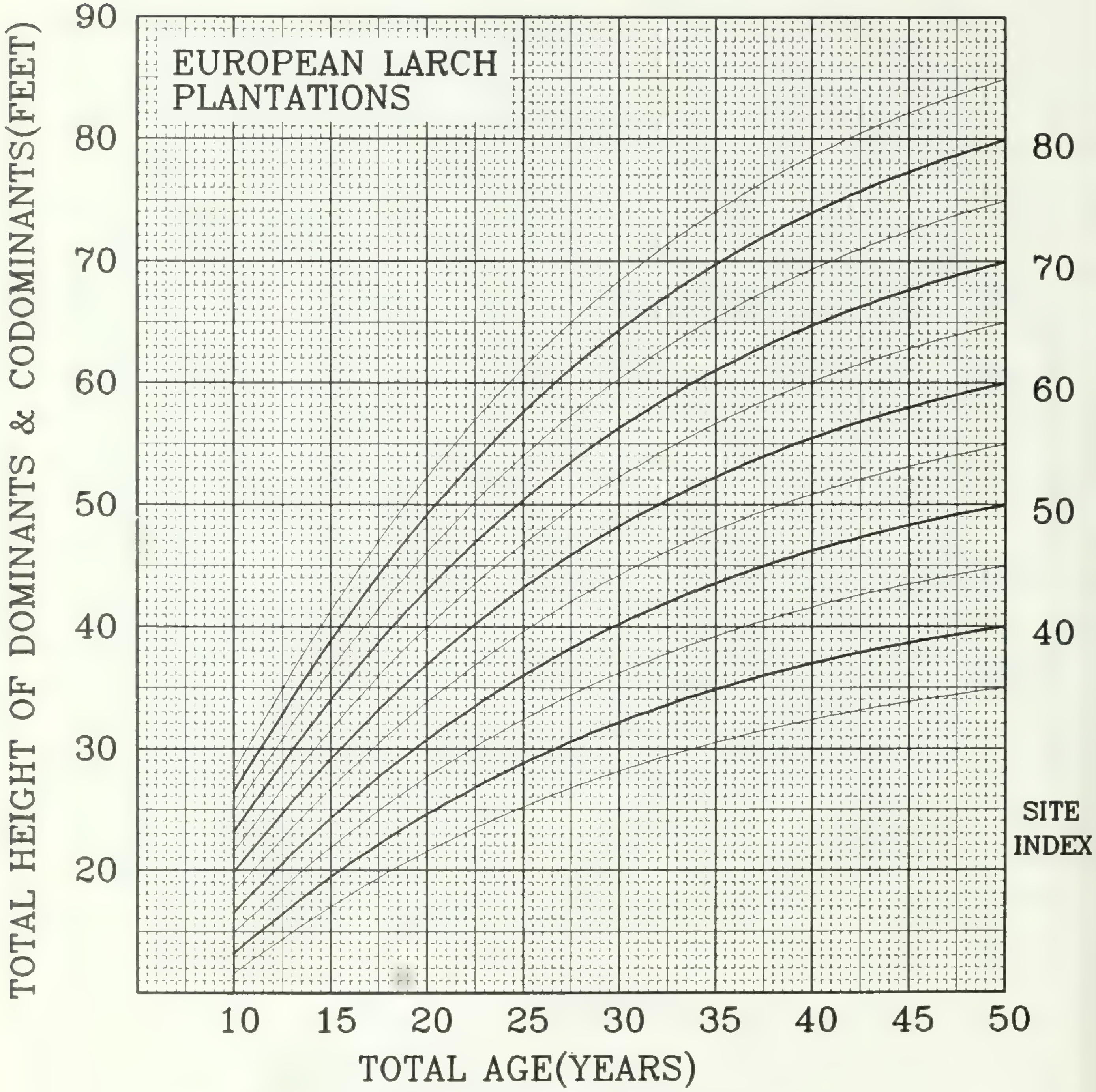

Figure 59.—European larch plantations (Aird and Stone 1955, Stone 1957)
New York and southern New England
147 plots, number of dominants and codominants not given
Total height and total age, anamorphic, logarithm equation
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1151	1.0000	-0.0504	1.3076	0.0009	0.98	0.72	4.2
SI	0.8821	1.0047	-0.0511	-1.4863	-0.0271	0.98	0.82	1.4

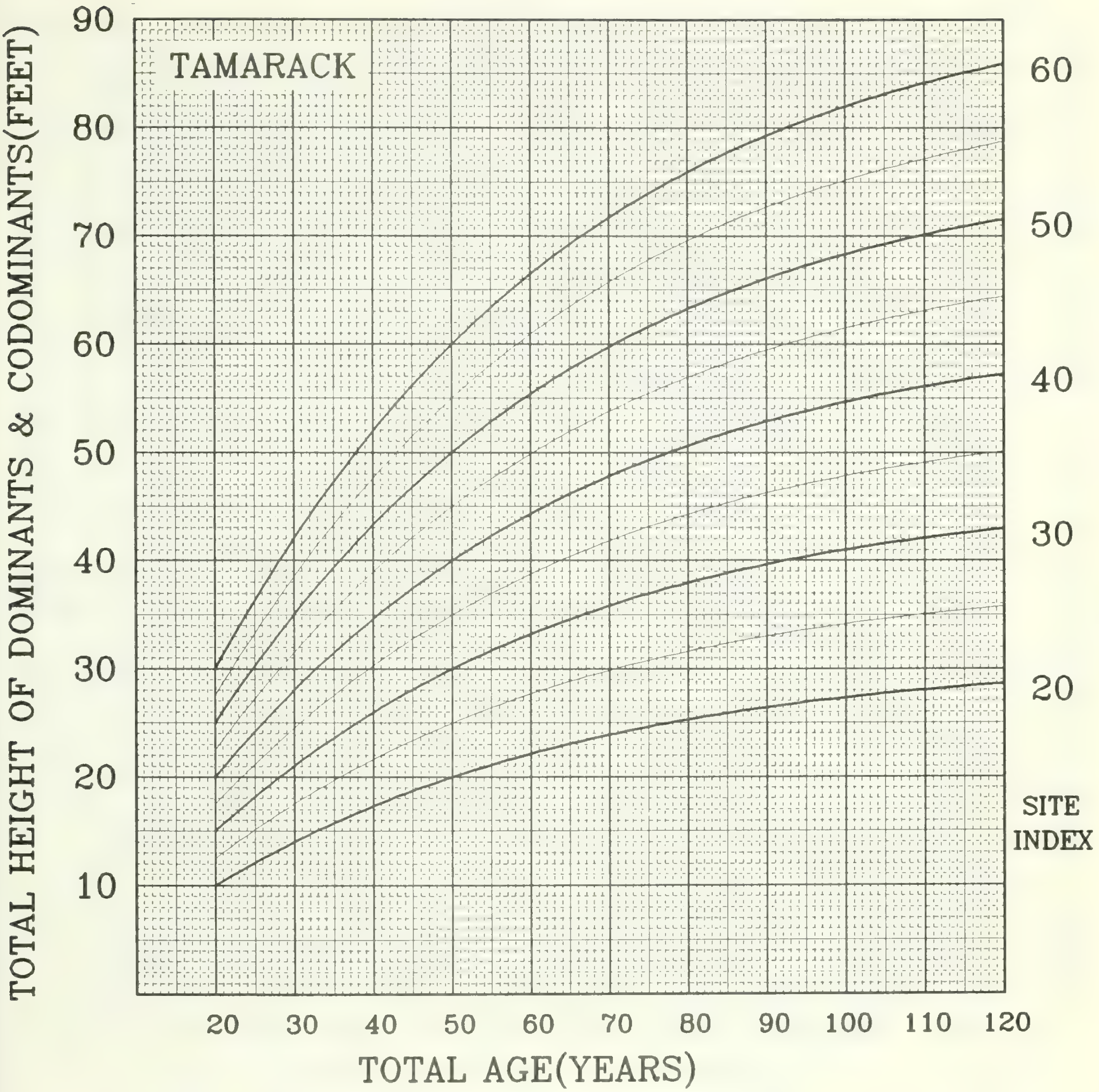

Figure 60.—Tamarack (Gevorkiantz 1957d)

Minnesota

Number of plots and number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50-90
Years:	12	10	7	5

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5470	1.0000	-0.0225	1.1129	0.0000	0.99	0.52	1.4
SI	0.6464	1.0000	-0.0225	-1.1129	0.0000	0.99	0.52	1.4

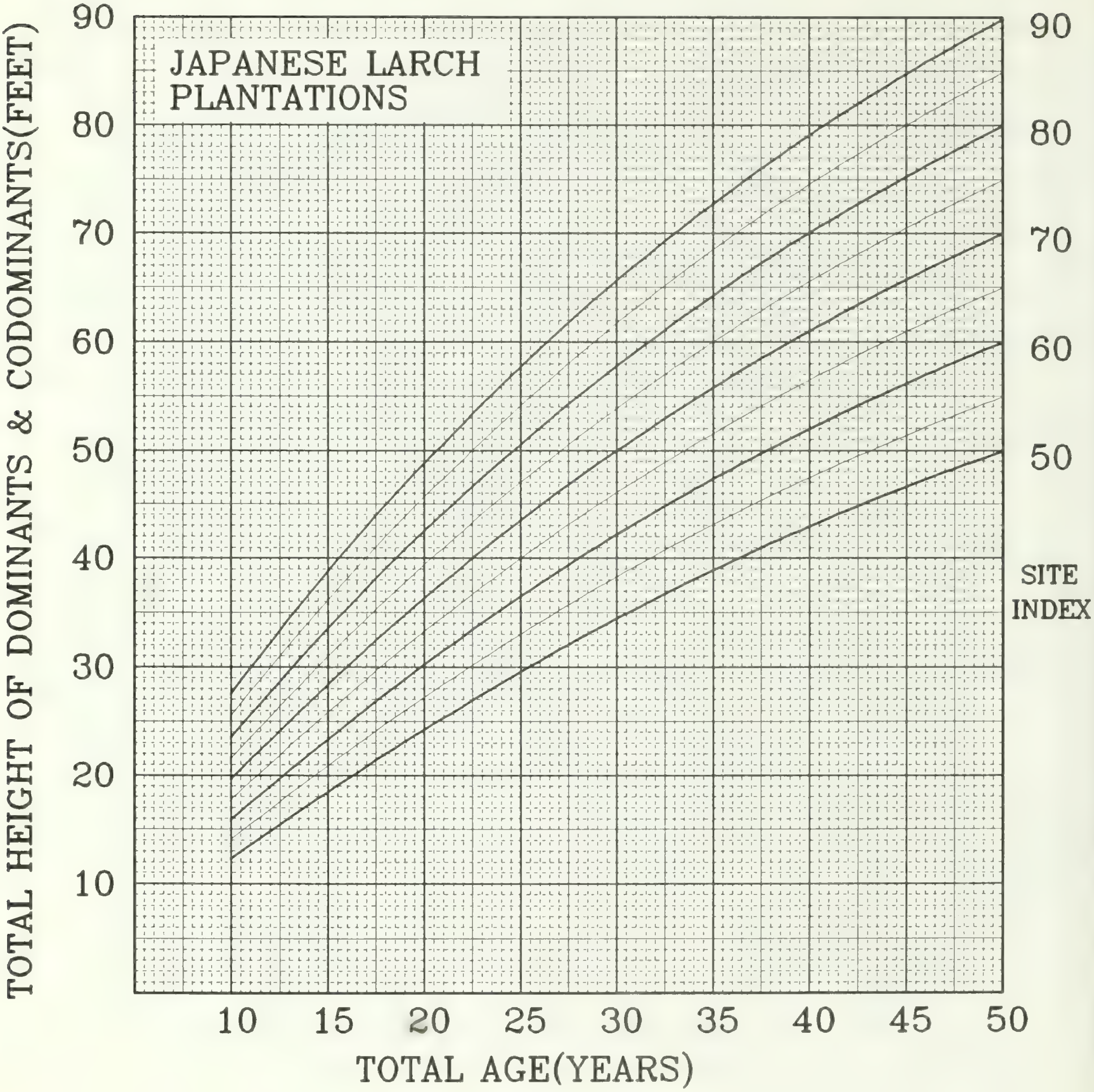

Figure 61.—Japanese larch plantations (Aird and Stone 1955, Stone 1957)
Southern portion of upper New York
25 plots, number of dominants and codominants not given
Total height and total age, anamorphic, logarithm equation not given
Add 3 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.5878	0.8755	-0.0220	3.5505	-0.2882	0.99	0.36	1.5
SI	0.1684	1.1840	-0.0051	-1.4894	-0.1879	0.99	0.83	3.7

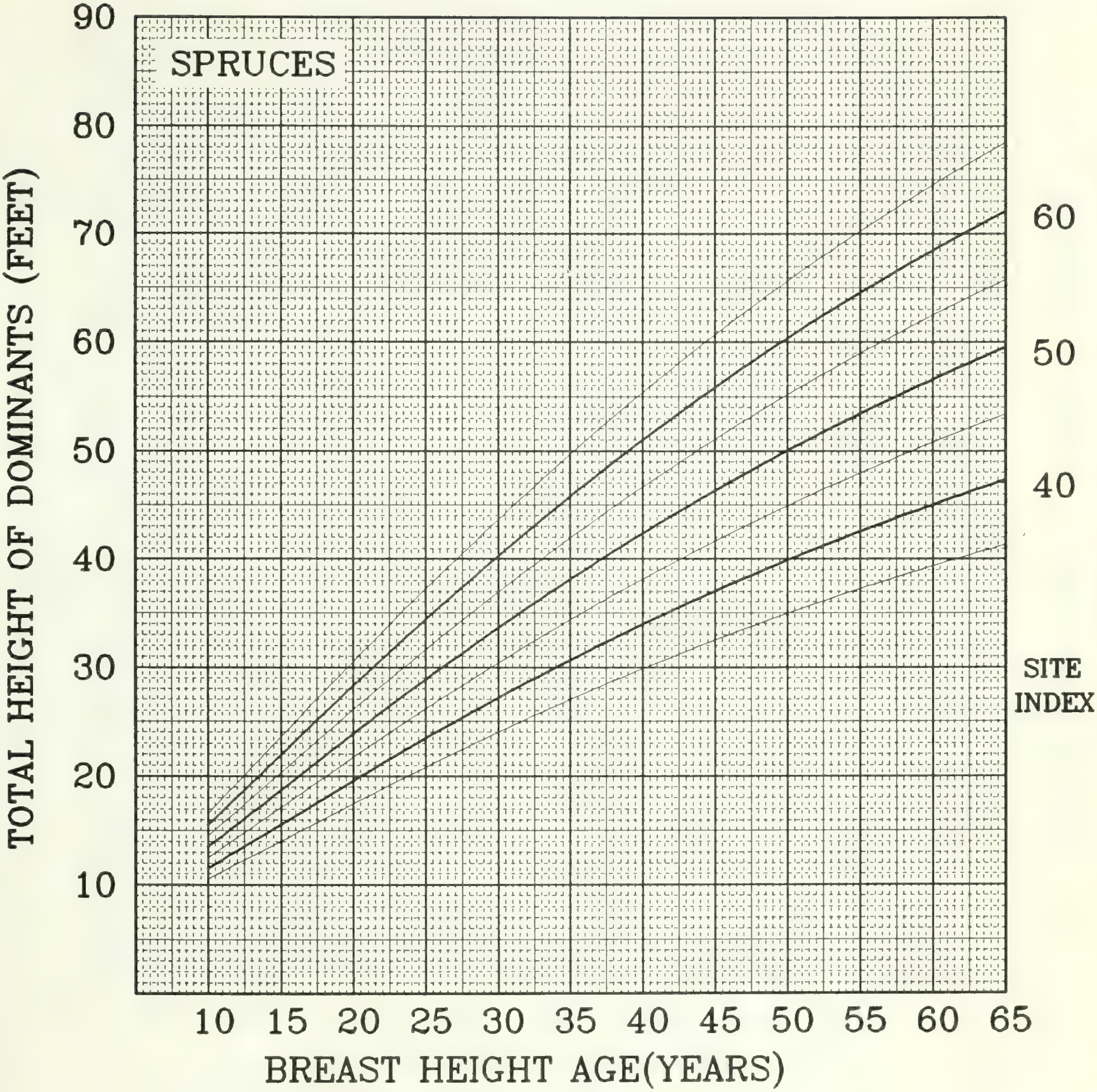

Figure 62.—Spruces (Griffin and Johnson 1980)
Northern Maine (Aroostock and Piscataquis Counties)
40 plots combining data for red, white, and black spruces; "six tallest trees" (dominants) on each plot; trees older than 45 years breast height age
Stem analysis, quadratic regression, polymorphic
Site index is height of dominant trees at 50 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0716	1.1276	-0.0018	1.2495	-0.0029	0.99	1.83	3.2
SI	0.0063	1.3985	-0.00024	-1.1102	-0.0944	0.99	2.11	4.0

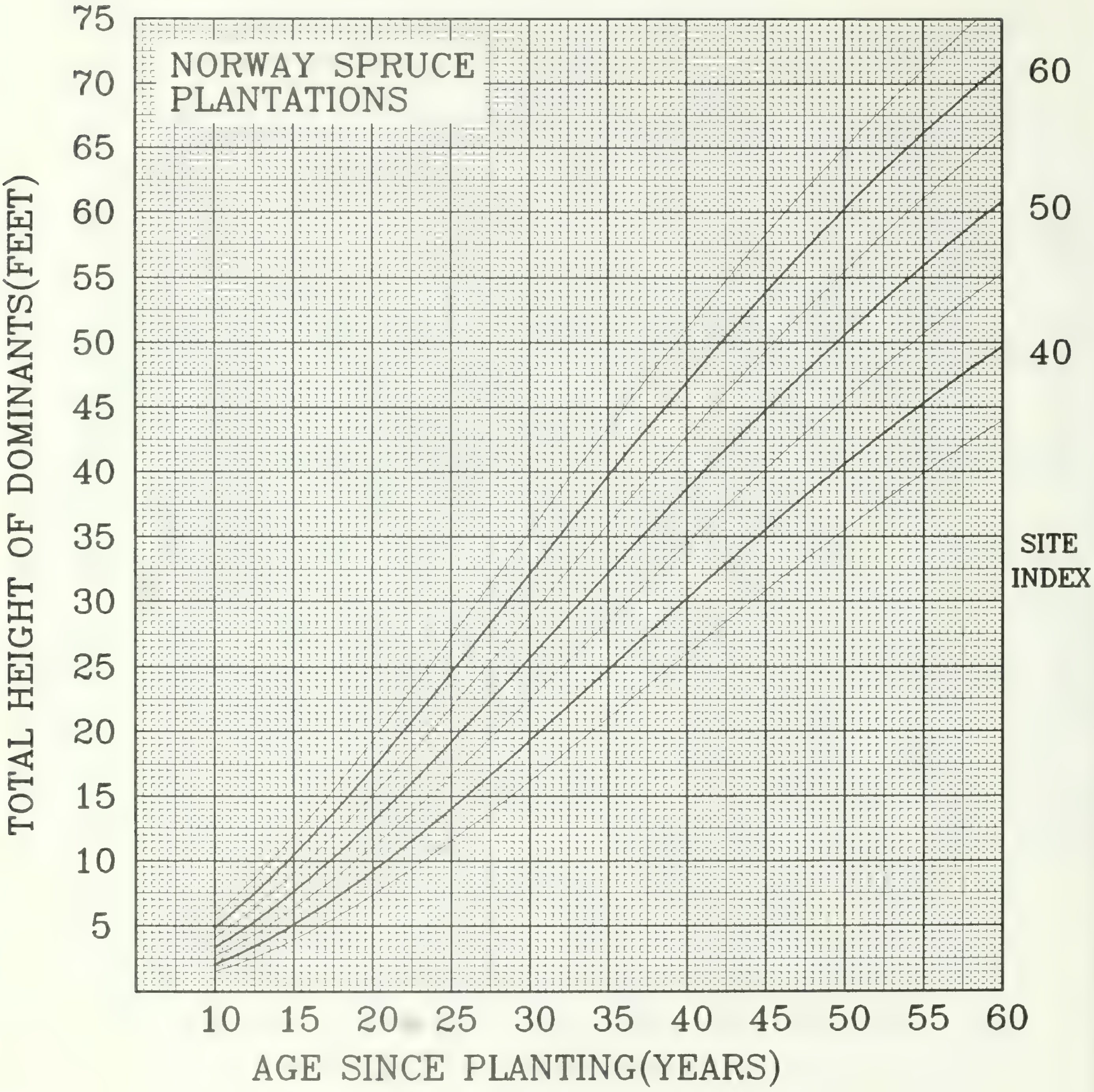

Figure 63.—Norway spruce plantations (Wilde *et al.* 1965)

Wisconsin

Number of plots and number of dominant trees not given

Total height and total age, anamorphic curves based on average of Wilde's two height growth curves

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40	50	60
Years:	17	15	13

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	6.7791	0.6876	-0.0280	12.1447	-0.4142	0.99	0.94	2.2
SI	0.0259	1.2496	-0.0021	-1.7841	-0.1088	0.97	1.81	3.8

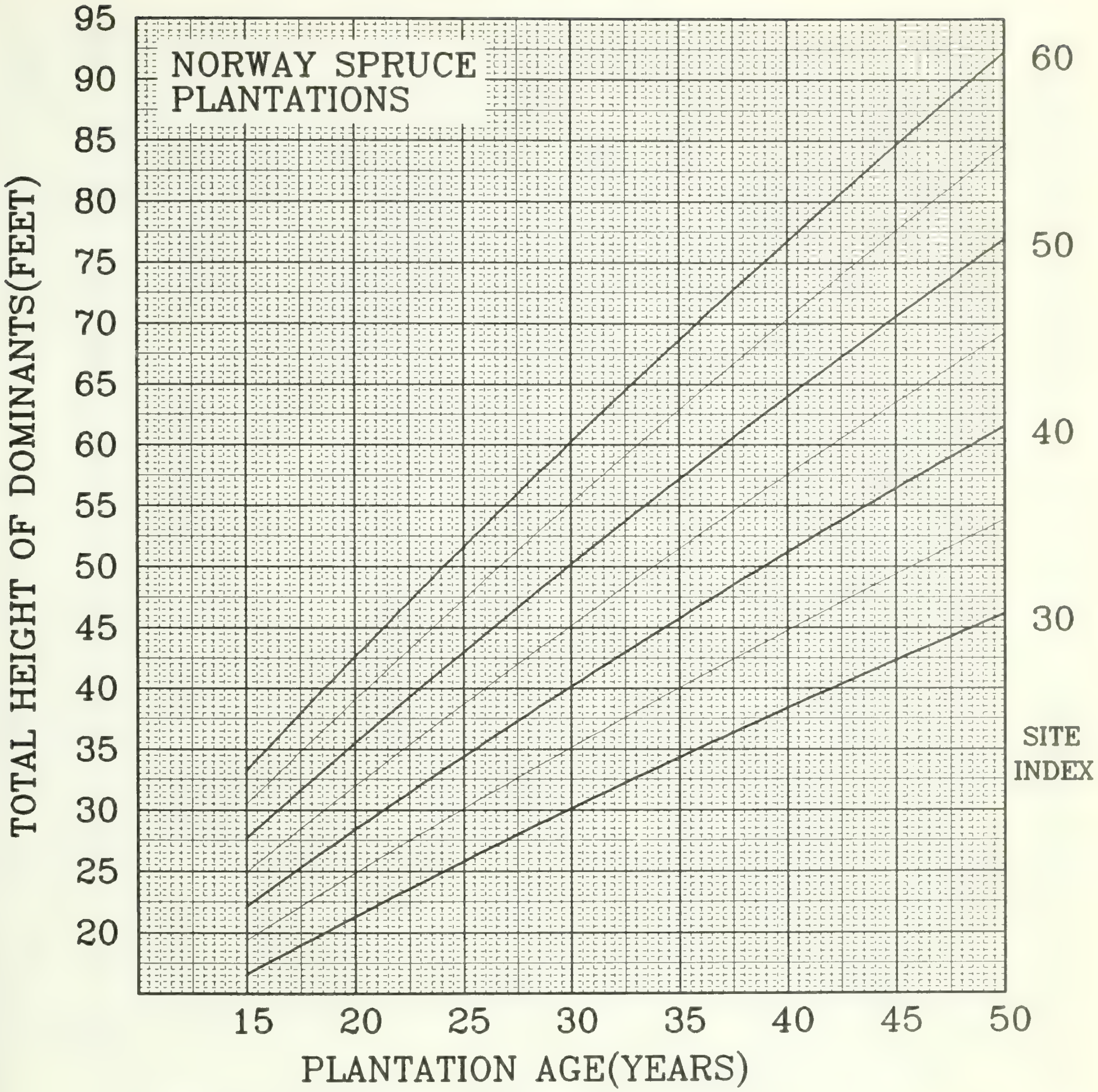

Figure 64.—Norway spruce plantations (Hannah 1972)
Vermont
99 plantations, number of dominant trees not given
Total height and plantation age, anamorphic, quadratic equation
Site index is total height at 30 years plantation age
Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	30	40	50	60
Years:	13	11	9	7

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	8.6744	0.9986	-0.0031	0.8904	-0.0006	0.99	1.04	2.8
SI	0.1149	0.6638	-0.0005	-0.5680	0.0958	0.99	0.55	2.3

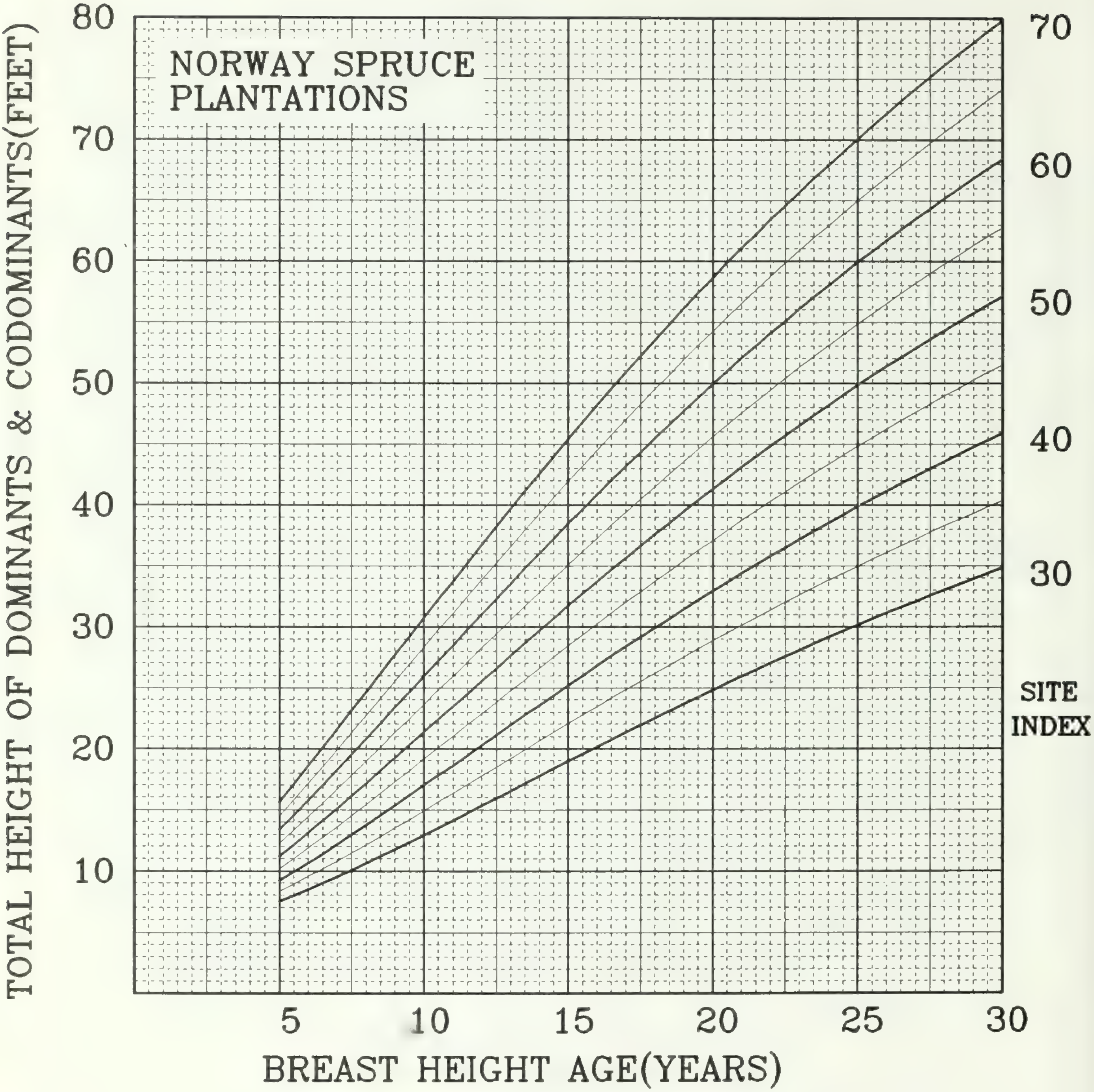

Figure 65.—Norway spruce plantations (Gordon, Williams, and Taylor 1989)
Southern Ontario
55 plots having 220 dominant and codominant trees
Stem analysis, site index prediction equations using Hegar (1968) model
Site index is total height of dominant and codominant trees at 25 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0854	0.9547	-0.0427	3.8109	-0.2288	0.98	1.22	1.4
SI	0.7847	0.9416	-0.0680	-0.8085	0.2206	0.99	2.14	5.3

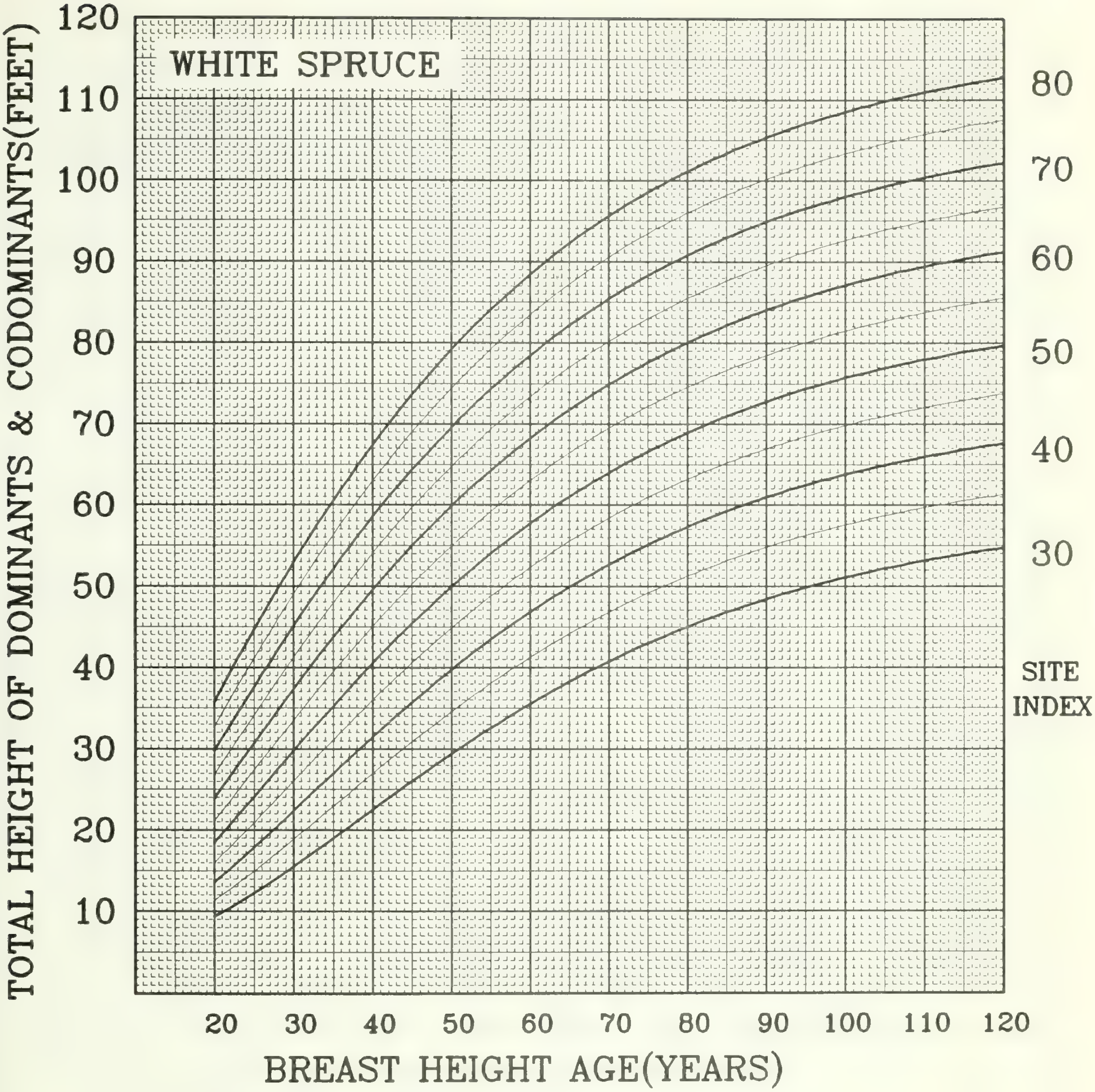

Figure 66.—White spruce (Gevorkiantz 1957g)
Minnesota
Number of plots and number of dominant and codominant trees not given
Total height and breast height age, anamorphic, equation not given
Site index is total height of dominant and codominant trees at 50 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	4.4803	0.7382	-0.0289	26.6132	-0.6461	0.99	1.60	3.0
SI	0.0816	1.3801	-0.0119	-3.5684	-0.2906	0.99	2.05	3.4

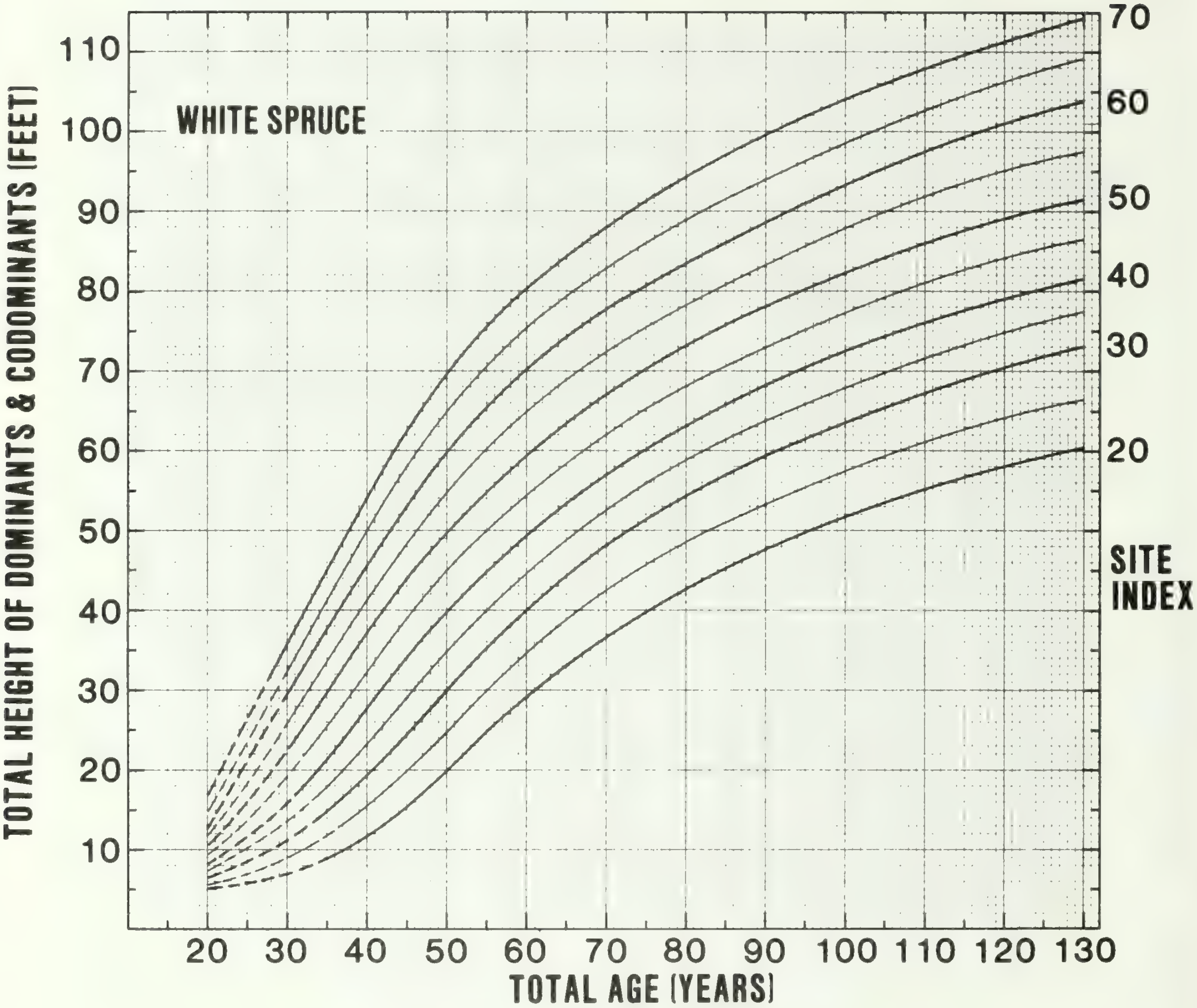

Figure 67.—White spruce (Carmean and Hahn 1981, revision of Gevorkiantz 1957g)
Minnesota
Number of plots and number of dominant and codominant trees not given
Total height and breast height age, anamorphic, Gevorkiantz (1957g) equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60	70
Years:	15	13	11	10	9	8

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	11.3079	0.5419	-0.0345	34.1568	-0.6078	0.99	2.18	6.4
SI	0.0380	1.5142	-0.0124	-6.4840	-0.3550	0.99	2.29	6.4

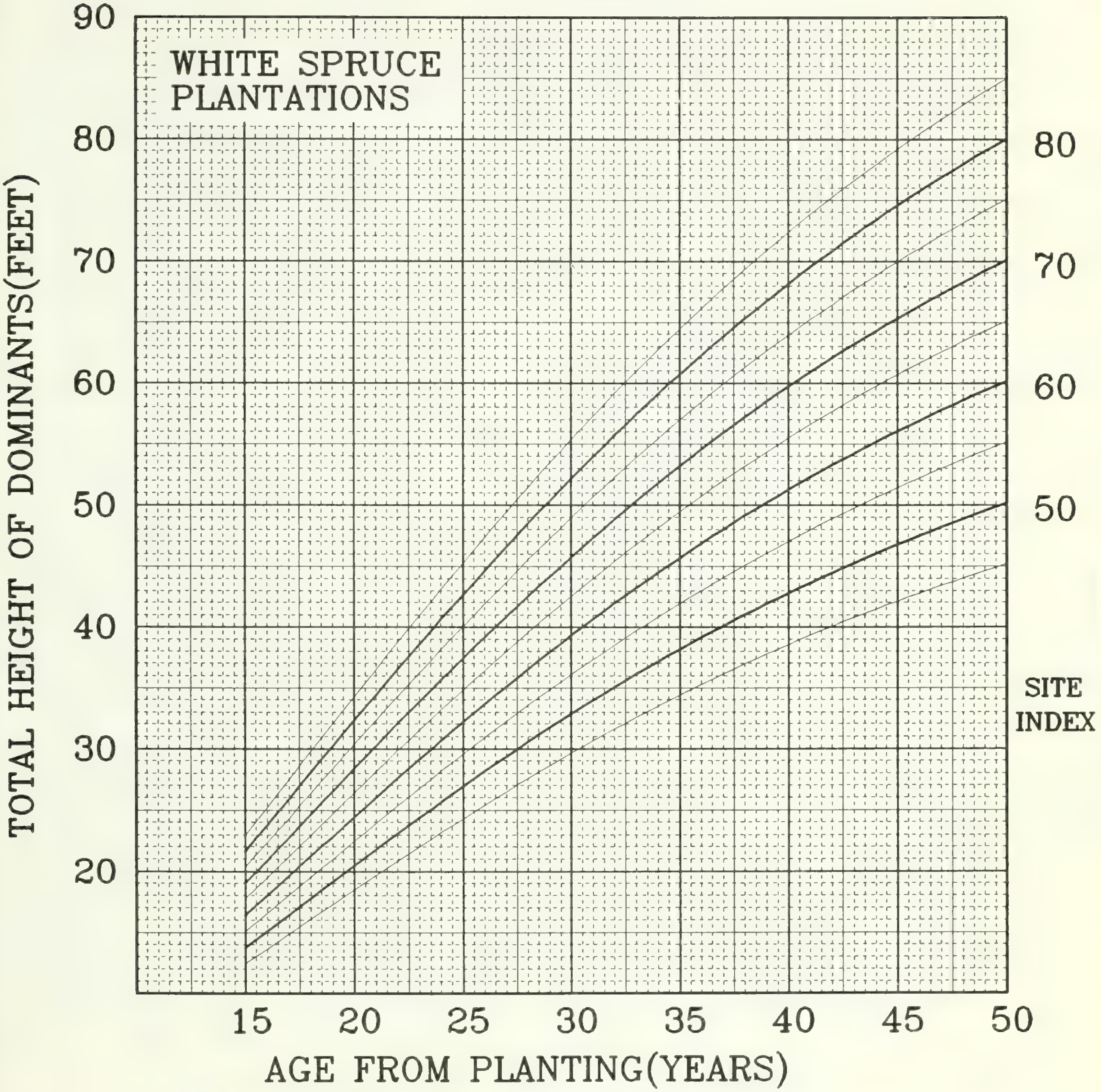

Figure 68.—White spruce plantations (Stiell and Berry 1973a, Berry 1978)
Ontario—Petawawa
46 permanent growth study plots, number of dominant trees not given
Plot remeasurements, quadratic equation not given, anamorphic
Site index is total height at 50 years from planting
Add 5 years to d.b.h. age to obtain age from planting (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3342	1.0008	-0.0401	1.8068	0.0248	0.97	1.07	2.1
SI	0.7485	0.9939	-0.0383	-1.7116	0.0320	0.99	1.38	4.2

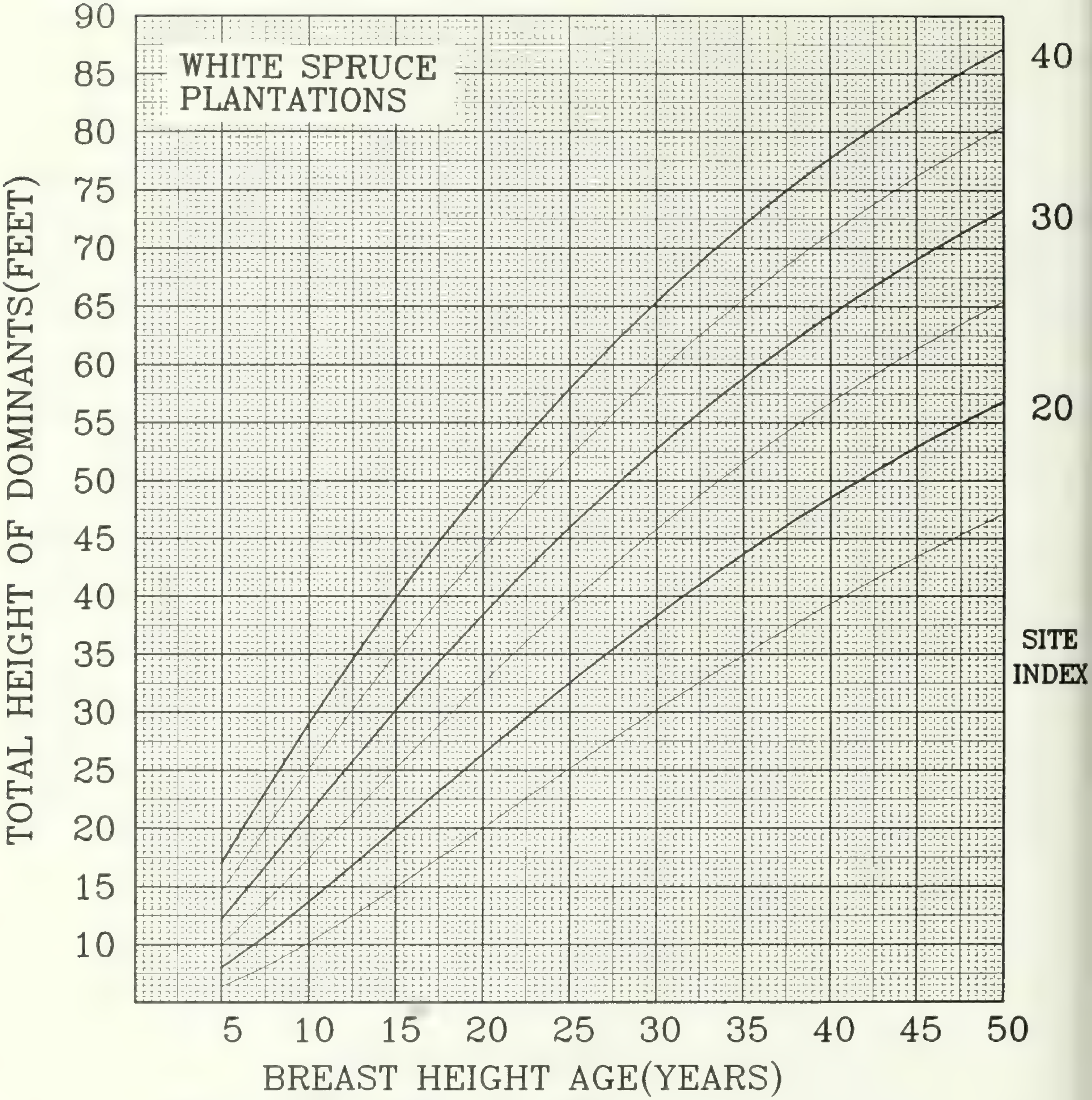

Figure 69.—White spruce plantations (Thrower 1986b)
North central Ontario
46 plots having 3 dominant trees per plot
Internode measurements and stem analysis, nonlinear regression, polymorphic
Site index is total height at 15 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	20.3317	0.4049	-0.0275	7.2043	-0.5166	0.94	0.54	0.7
SI	0.00033	1.6606	-0.00025	-1.2755	-0.0715	0.99	1.35	3.6

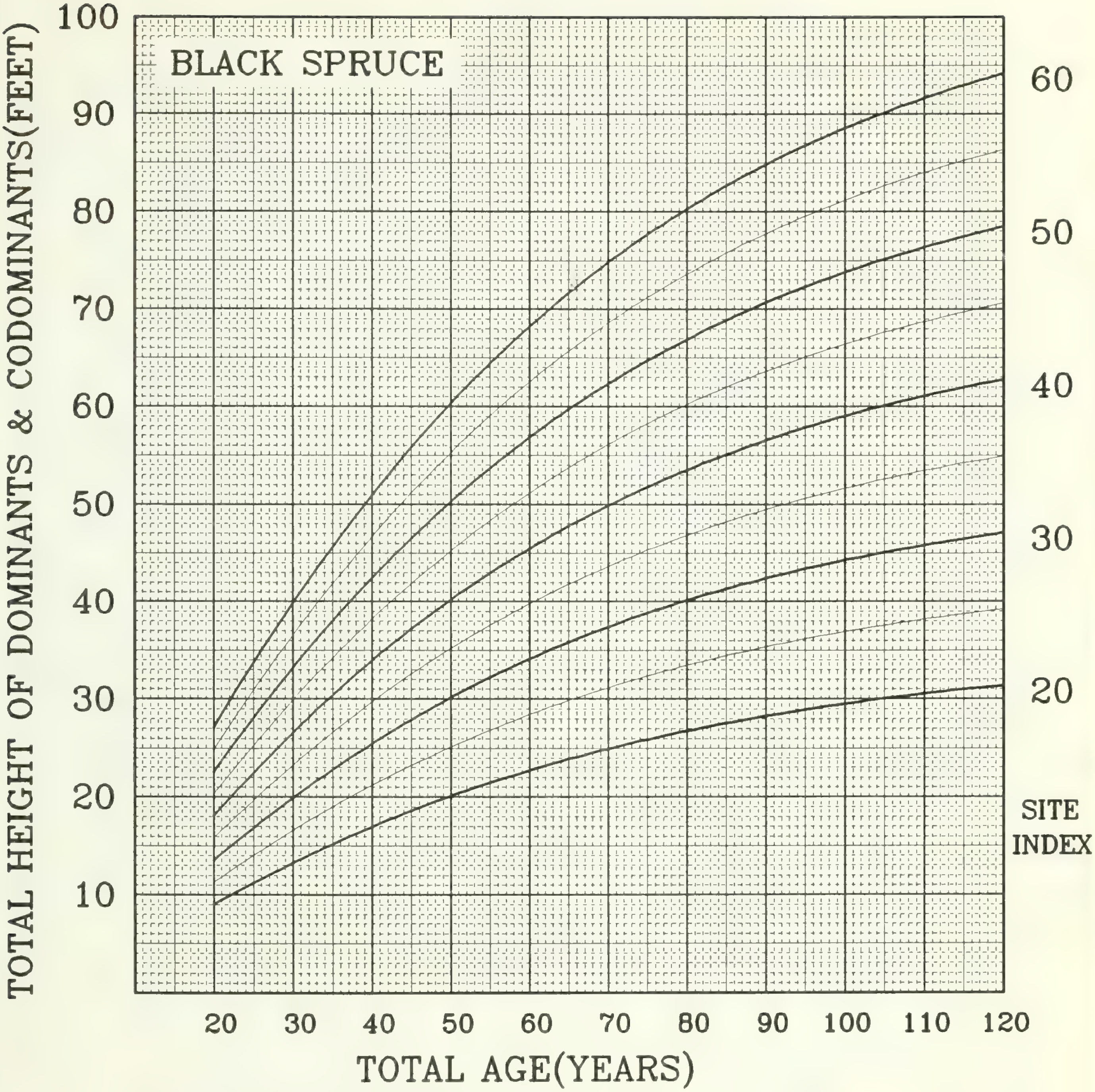

Figure 70.—Black spruce (Gevorkiantz 1957a, derived from Fox and Kruse 1939)
Northeastern Minnesota—Superior National Forest
Number of plots and number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60	70	80	90
Years:	15	13	11	10	9	8	7	6

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.7620	1.0000	-0.0201	1.2307	0.0000	0.99	0.72	1.9
SI	0.5675	1.0000	-0.0201	-1.2307	0.0000	0.99	0.72	1.9

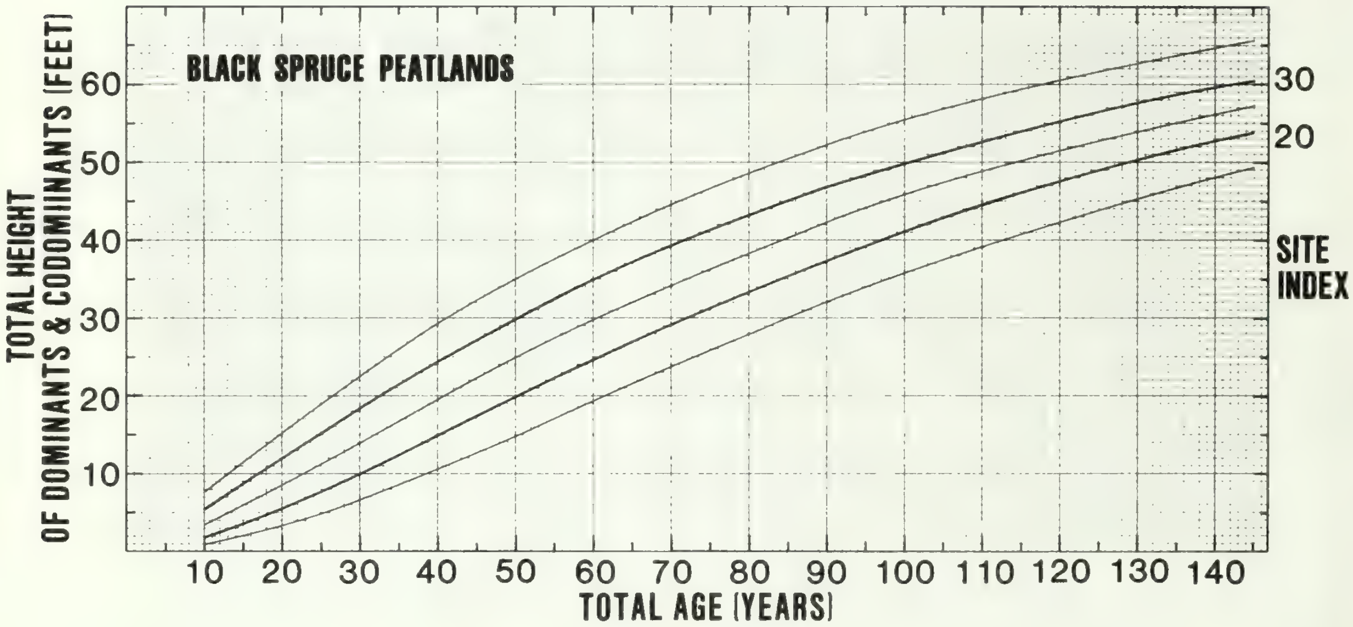

Figure 71.—Black spruce peatlands (Payandeh 1978)
Ontario Clay Belt
Number of plots not given, 60 dominant and codominant trees
Stem analysis, polymorphic, nonlinear regression
Add 15 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	16.2120	0.4580	-0.0135	8.0105	-0.5321	0.99	1.22	2.9
SI	0.0008	1.8529	-0.00016	-1.7043	-0.1933	0.99	1.66	7.4

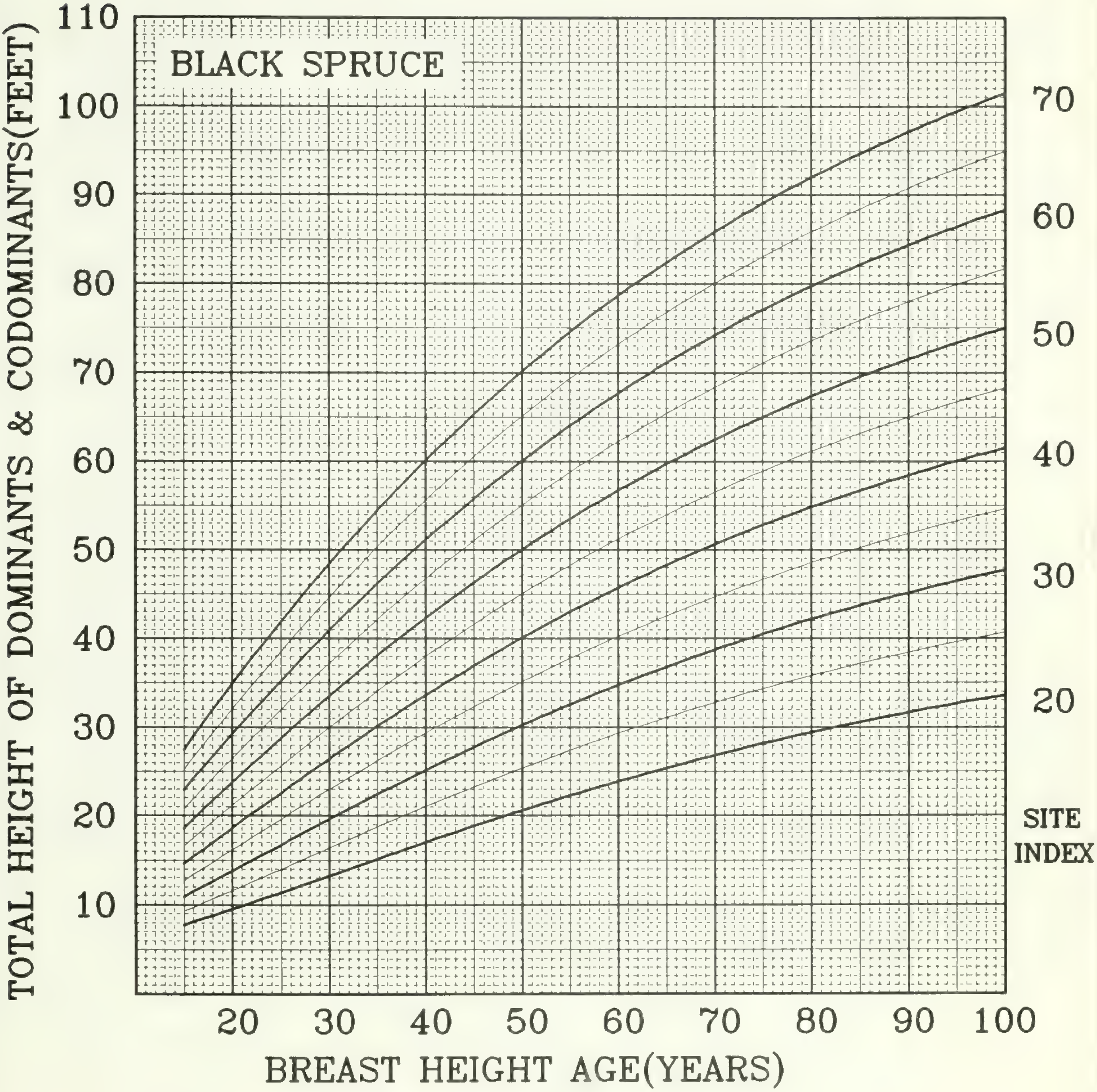

Figure 72.—Black spruce (Thrower 1986a)

North central Ontario, mineral soils
44 plots having 2 to 5 dominant and codominant trees per plot
Stem analysis, nonlinear regression, polymorphic
Site index is total height at 50 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.9232	0.8737	-0.0178	4.6529	-0.3319	0.97	0.40	0.2
SI	0.1324	1.1955	-0.0061	-1.2545	-0.0943	0.99	1.31	4.1

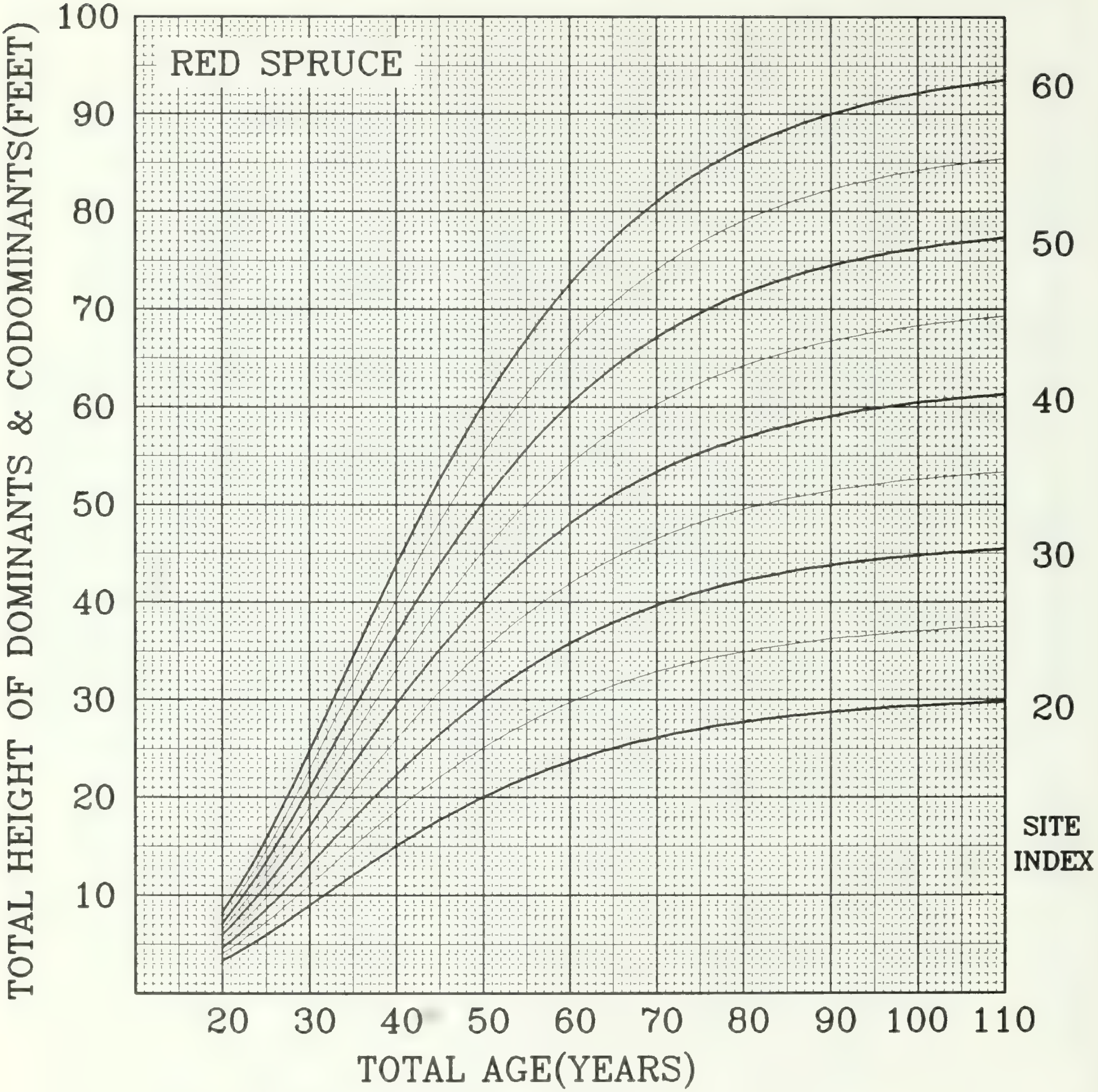

Figure 73.—Red spruce (Meyer 1929)
Maine, New Hampshire, and Vermont
201 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given,
original curves revised from SI age 65 to SI age 50 years
Add 15 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3307	1.0442	-0.0496	3.5829	0.0945	0.99	1.19	4.0
SI	0.9333	0.9124	-0.0585	-3.1832	0.2184	0.99	0.91	3.7

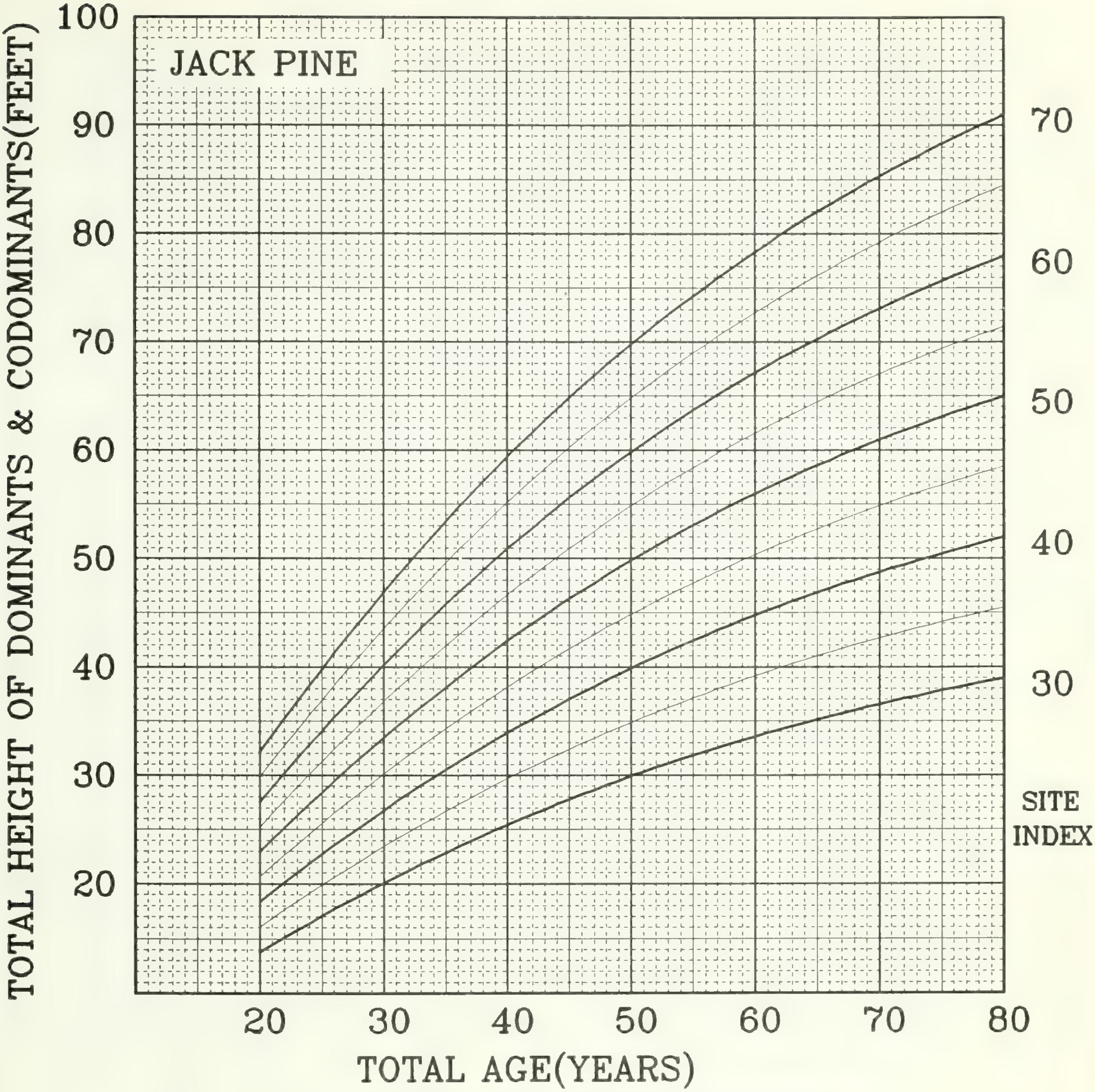

Figure 74.—Jack pine (Gevorkiantz 1956c, derived from Wackerman *et al.* 1929, and from Eyre and LeBarron 1944)

Lake States

Number of plots and number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30	40	50	60	70	80	90
Years:	9	8	7	6	5	4	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.6330	1.0000	-0.0223	1.2419	0.0000	0.99	0.50	1.1
SI	0.6124	1.0000	-0.0223	-1.2419	0.0000	0.99	0.50	1.1

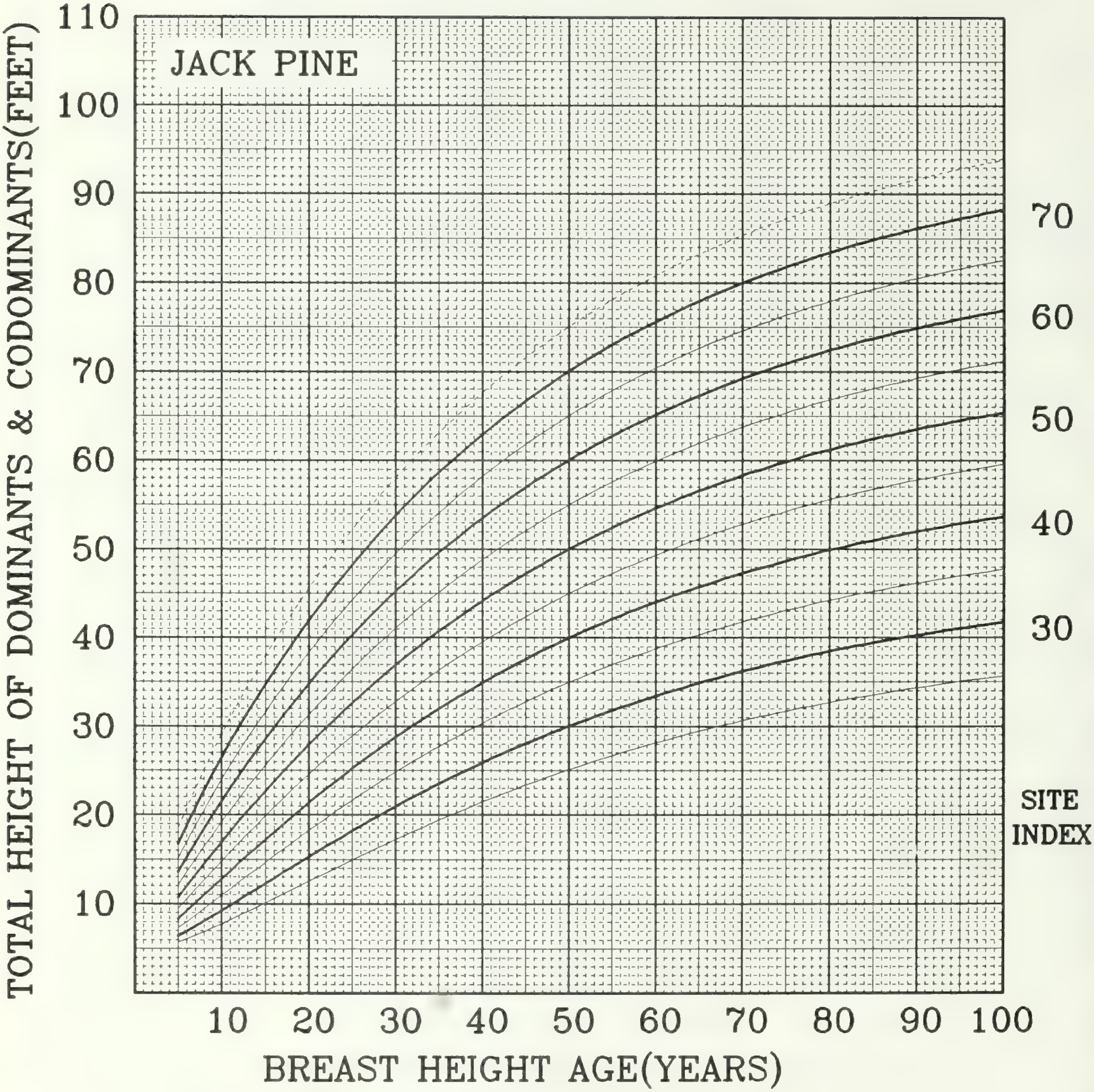

Figure 75.—Jack pine (Lenthall 1986, Carmean and Lenthall 1989)
North central Ontario
141 plots having 3 to 5 dominant and codominant trees per plot
Stem analysis, nonlinear regression, polymorphic
Site index is total height at 50 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0141	0.8989	-0.0236	7.9469	-0.5084	0.98	0.54	0.8
SI	0.1917	1.2234	-0.0092	-1.3627	-0.1764	0.99	1.54	3.2

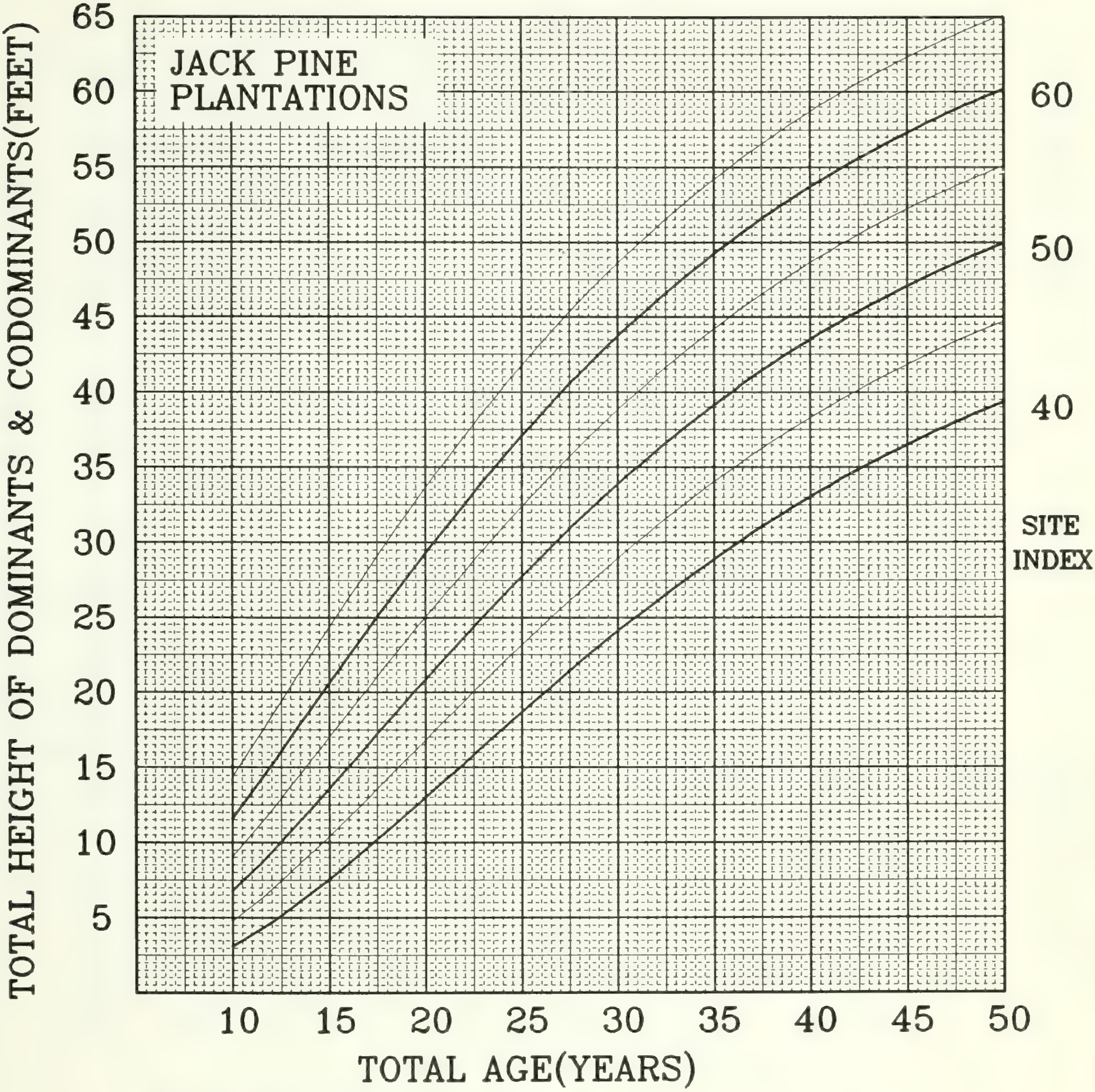

Figure 76.—Jack pine plantations (Wilde *et al.* 1965)
Wisconsin
44 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Add 4 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.3102	0.8350	-0.0512	152.9926	-1.0625	0.97	1.44	2.6
SI	0.8618	0.9312	-0.0190	-1.8004	0.1877	0.98	2.42	3.7

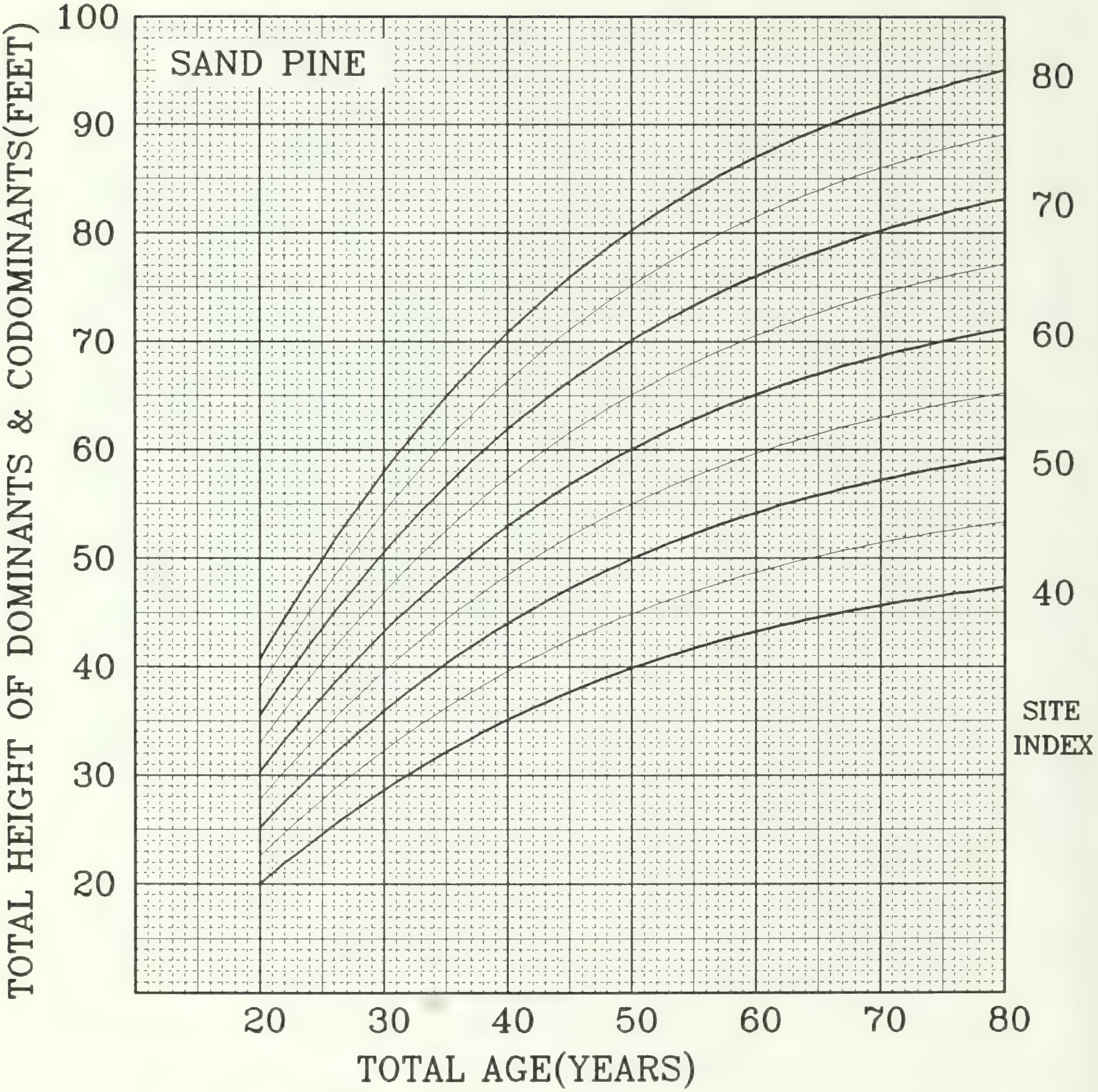

Figure 77.—Sand pine (Schumacher and Coile 1970)
Florida—Ocala National Forest
54 plots having 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Add 5 years to d.b.h. age to obtain total age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2660	1.0034	-0.0365	1.5515	-0.0221	0.99	0.63	1.7
SI	0.7523	1.0085	-0.0360	-1.7997	-0.0657	0.99	0.67	2.2

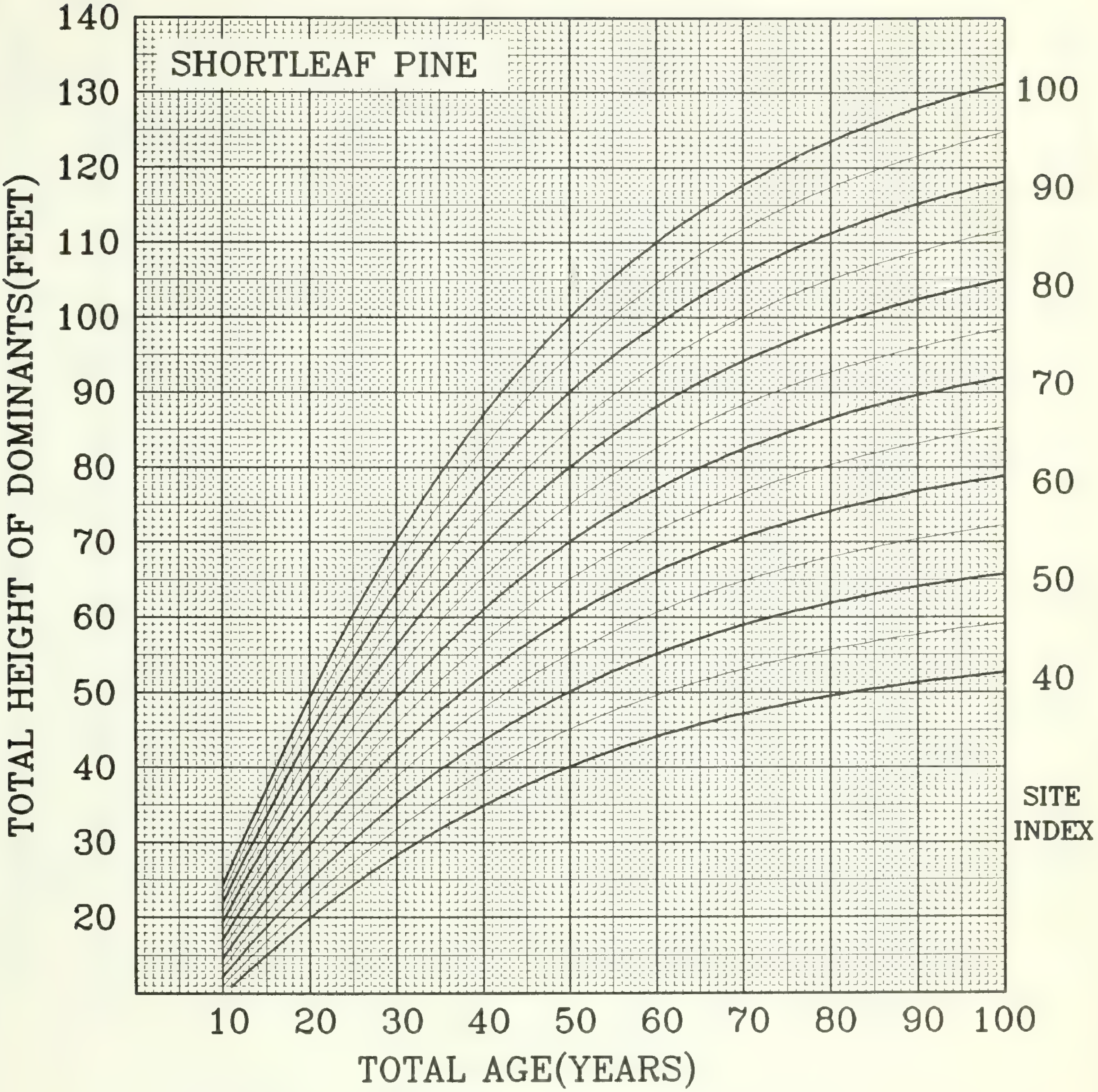

Figure 78.—Shortleaf pine (USDA 1929)

Southern States

188 plots, number of dominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40-55	56-75	76+
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4232	0.9989	-0.0285	1.2156	0.0088	0.99	0.37	1.7
SI	0.7286	0.9946	-0.0296	-1.1733	0.0266	0.99	0.51	2.4

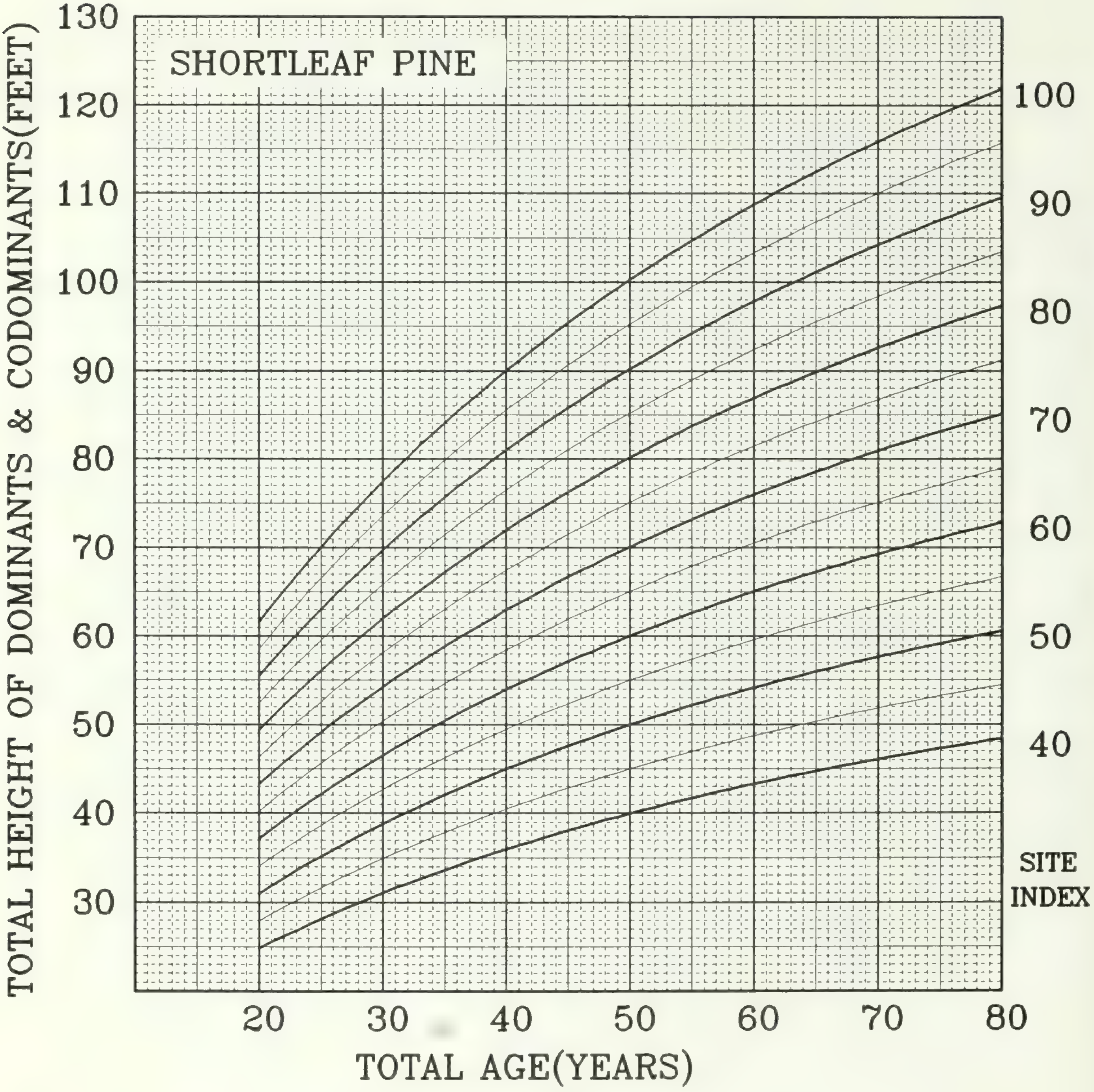

Figure 79.—Shortleaf pine (Schumacher and Coile 1960)
North Carolina Piedmont
74 plots having 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30-55	56-75	76+
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4809	1.0145	-0.0142	0.6040	0.0242	0.99	0.50	1.5
SI	0.6161	0.9871	-0.0106	-0.5655	0.0174	0.99	0.26	0.8

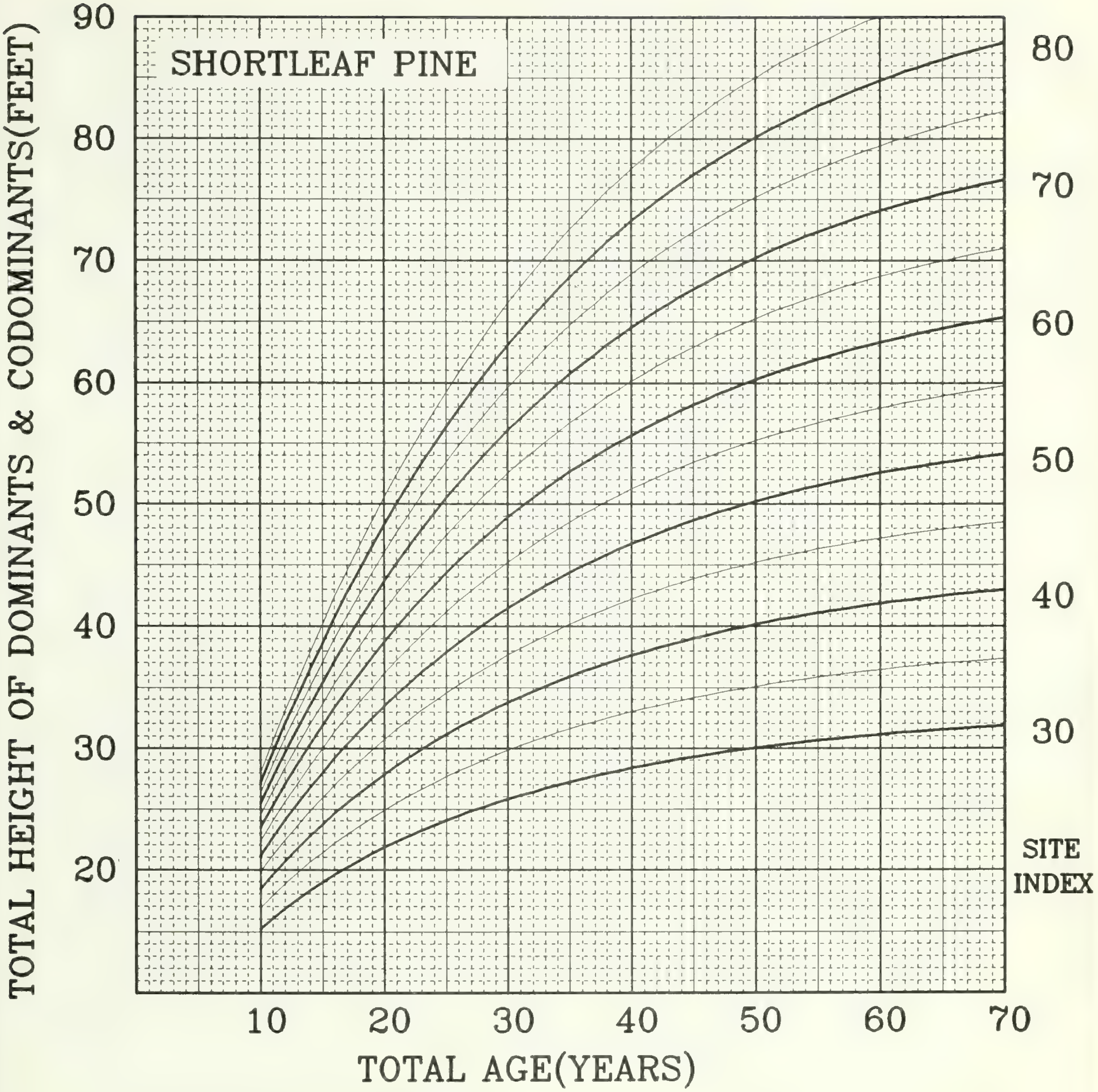

Figure 80.—Shortleaf pine (Nash 1963)

Southeastern Missouri—three areas averaged

309 plots having 7 dominant and codominant trees on each plot

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30-55	56-75	76+
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.8977	1.0624	-0.0398	0.1419	0.4709	0.99	1.00	3.2
SI	0.9506	0.9859	-0.0562	-0.6048	0.2444	0.99	1.55	4.9

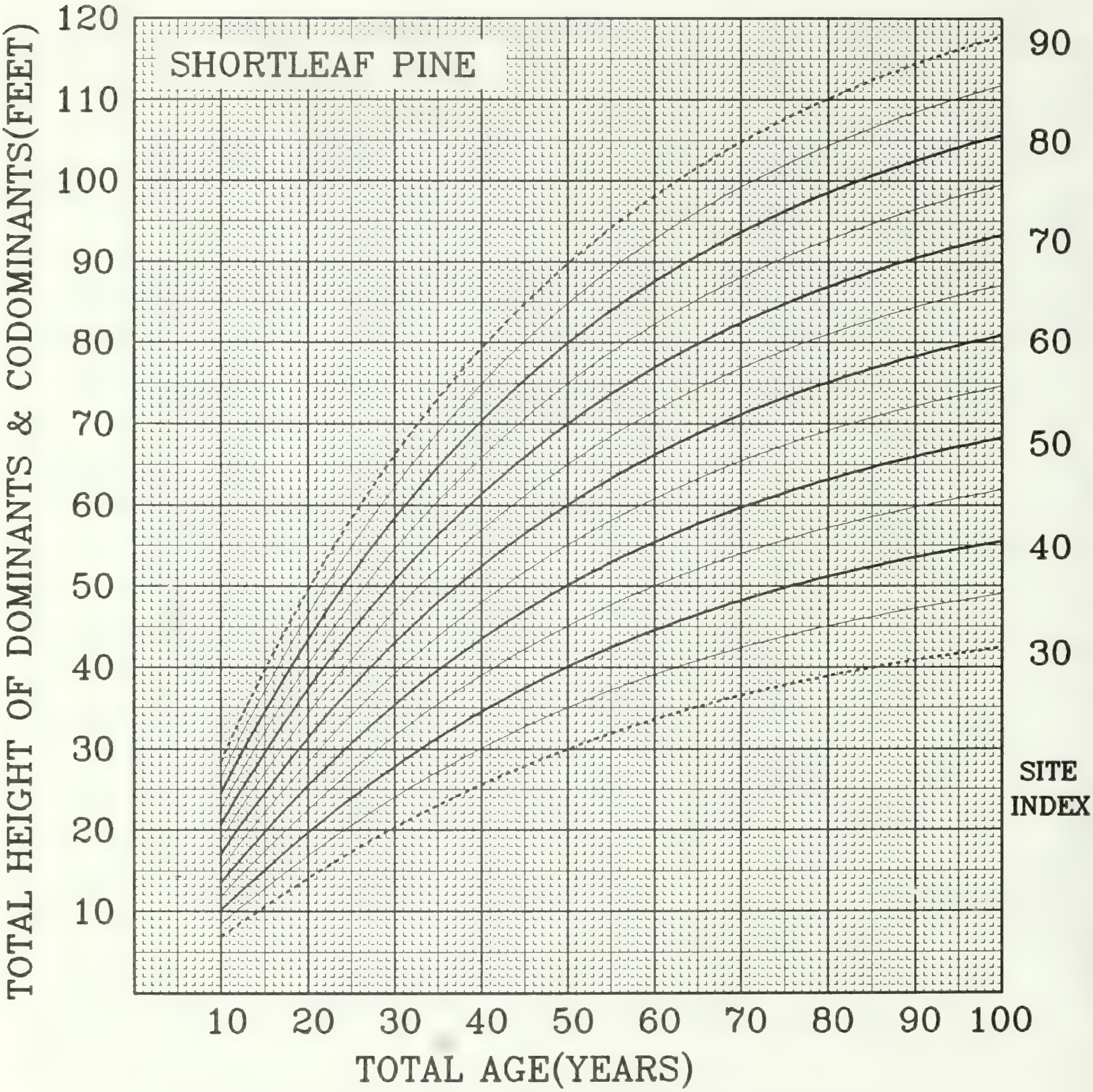

Figure 81.—Shortleaf pine (Graney and Burkhart 1973)

Ouachita Mountains of west-central Arkansas and southeastern Oklahoma

216 plots having 2 dominant and codominant trees on each plot

Stem analysis, nonlinear regression, polymorphic

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	30-55	56-75	76+
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.2746	0.9019	-0.0220	2.1554	-0.2208	0.99	0.82	1.8
SI	0.4280	1.0711	-0.0139	-1.3230	-0.12069	0.99	1.13	3.6

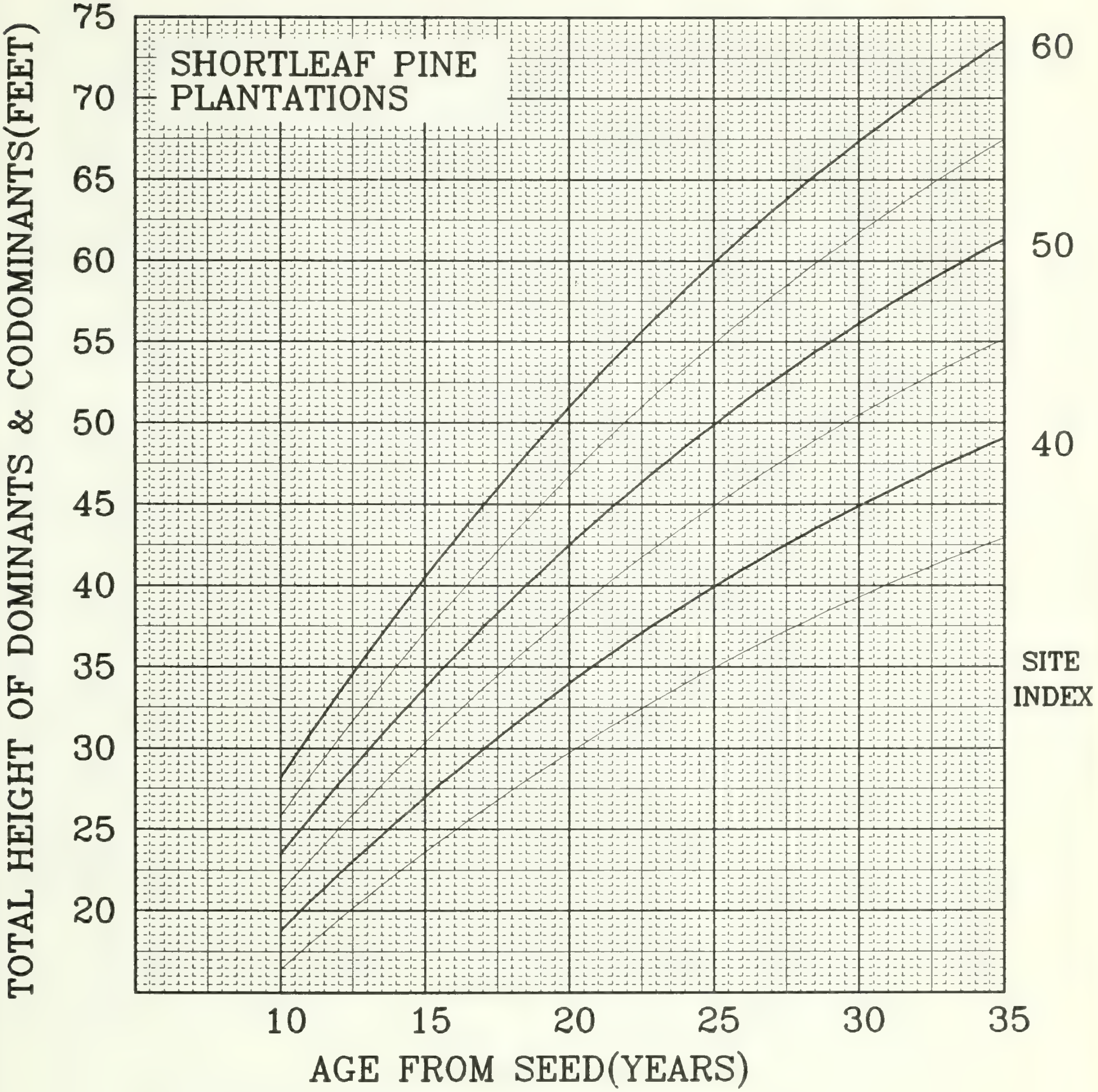

Figure 82.—Shortleaf pine plantations (Smalley and Bower 1971)
Central Tennessee, Northern Alabama, and Northwest Georgia
104 plantations, number of dominant trees not given
Total height and age from seed, anamorphic, logarithm equation
Site index is total height at 25 years age from seed
Convert d.b.h. age to age from seed by adding years according to site index (BH = 0.0):

SI:	<40	40-55	>55
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.7327	0.9998	-0.0384	1.1430	-0.0004	0.99	0.28	0.6
SI	0.5383	1.0180	-0.0383	-1.2795	-0.0315	0.99	0.30	0.9

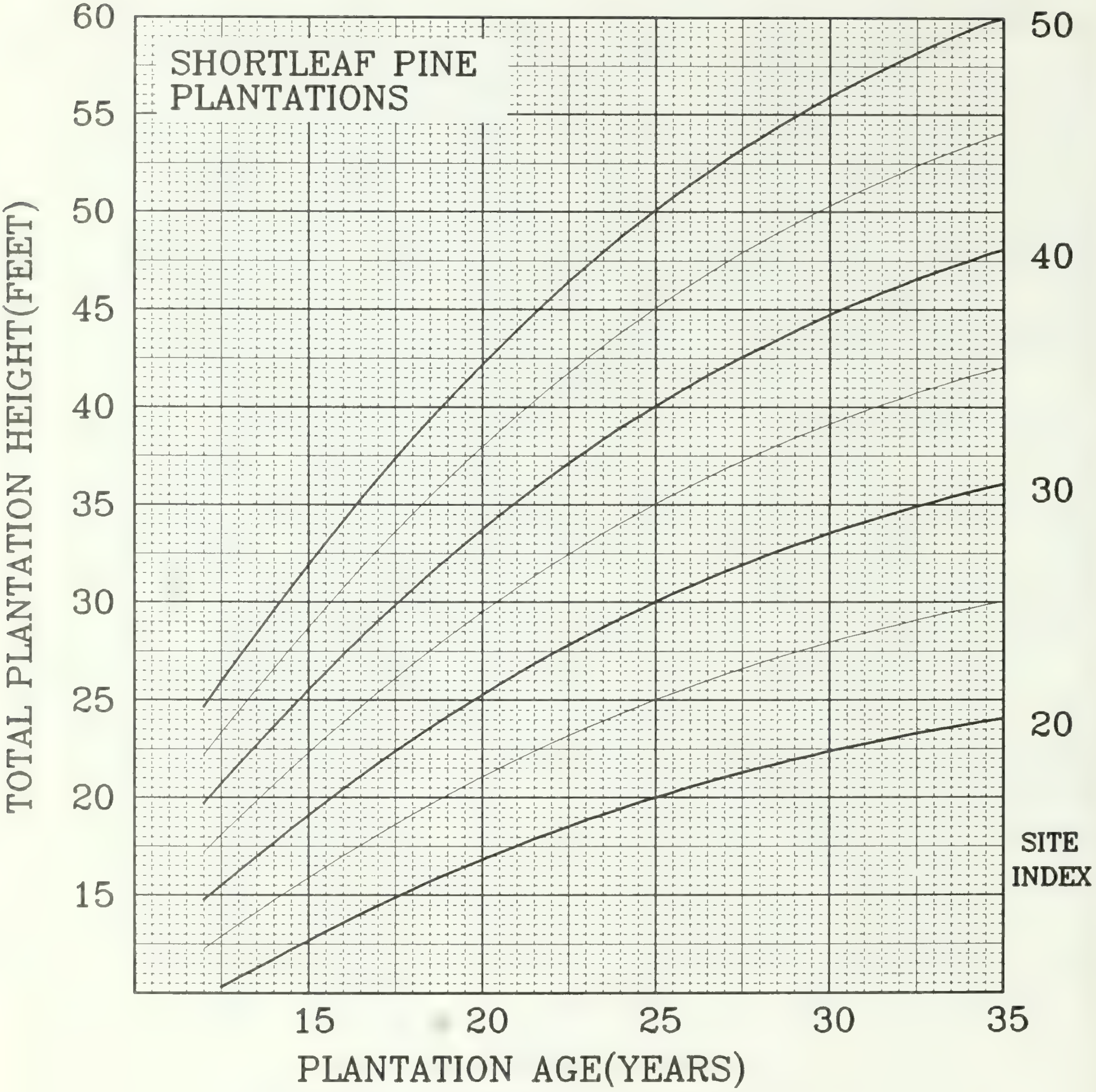

Figure 83.—Shortleaf pine plantations (Gilmore and Metcalf 1961b)

Southern Illinois

61 plantations, number of dominant and codominant trees not given

Total height and plantation age, anamorphic, logarithm equation

Site index is total height at plantation age of 25 years

Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	<25	25-40	>40
Years:	7	6	5

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4105	0.9977	-0.0747	2.0668	-0.0104	0.95	0.73	0.6
SI	0.6996	1.0078	-0.0761	-2.2217	-0.0262	0.95	0.71	0.8

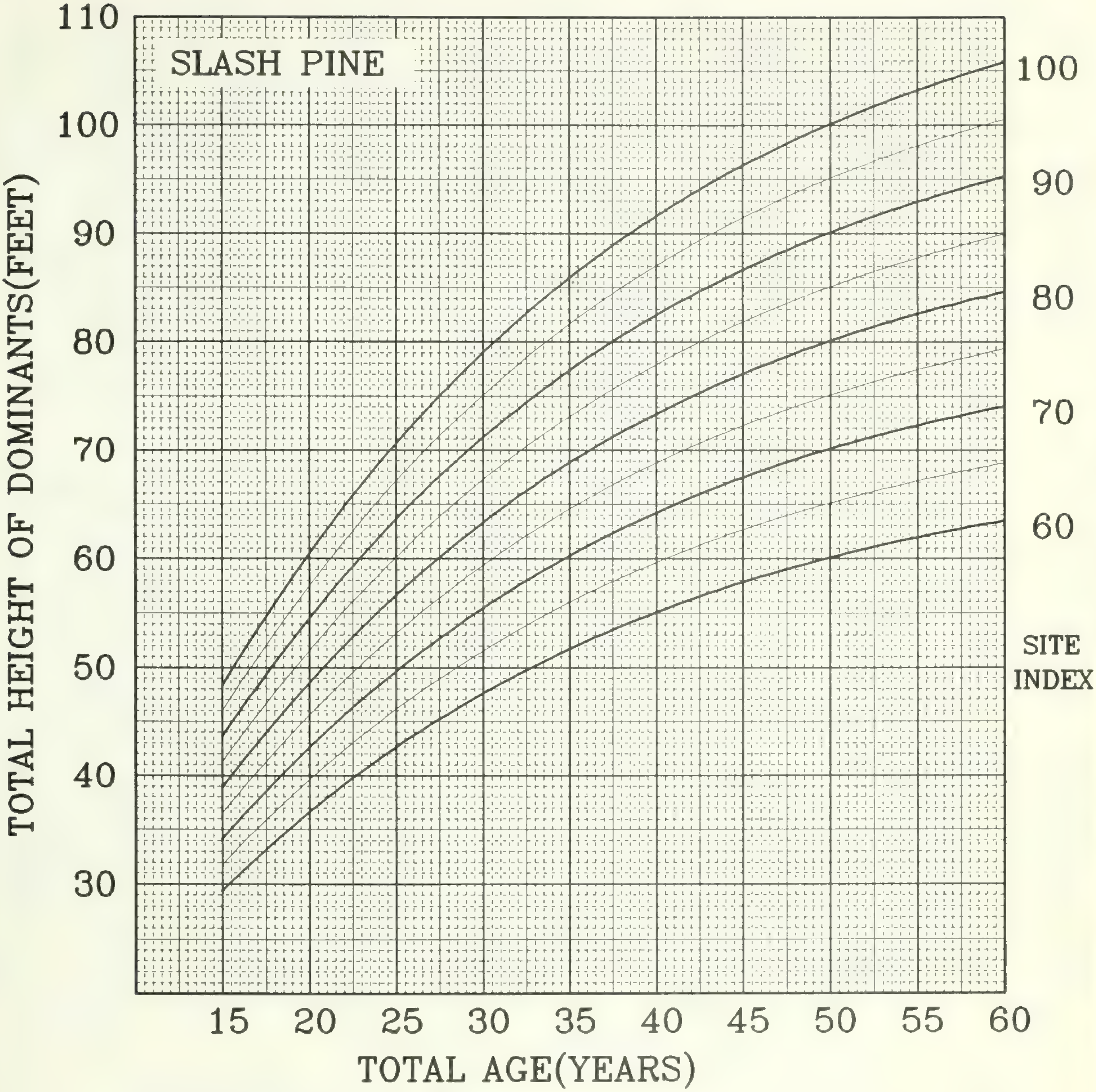

Figure 84.—Slash pine (USDA 1929)

Southern States

124 plots, number of dominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	75+
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1557	1.0031	-0.0408	0.9807	0.0314	0.99	0.37	0.7
SI	0.8565	1.0002	-0.0421	-1.1093	0.0124	0.99	0.45	1.0

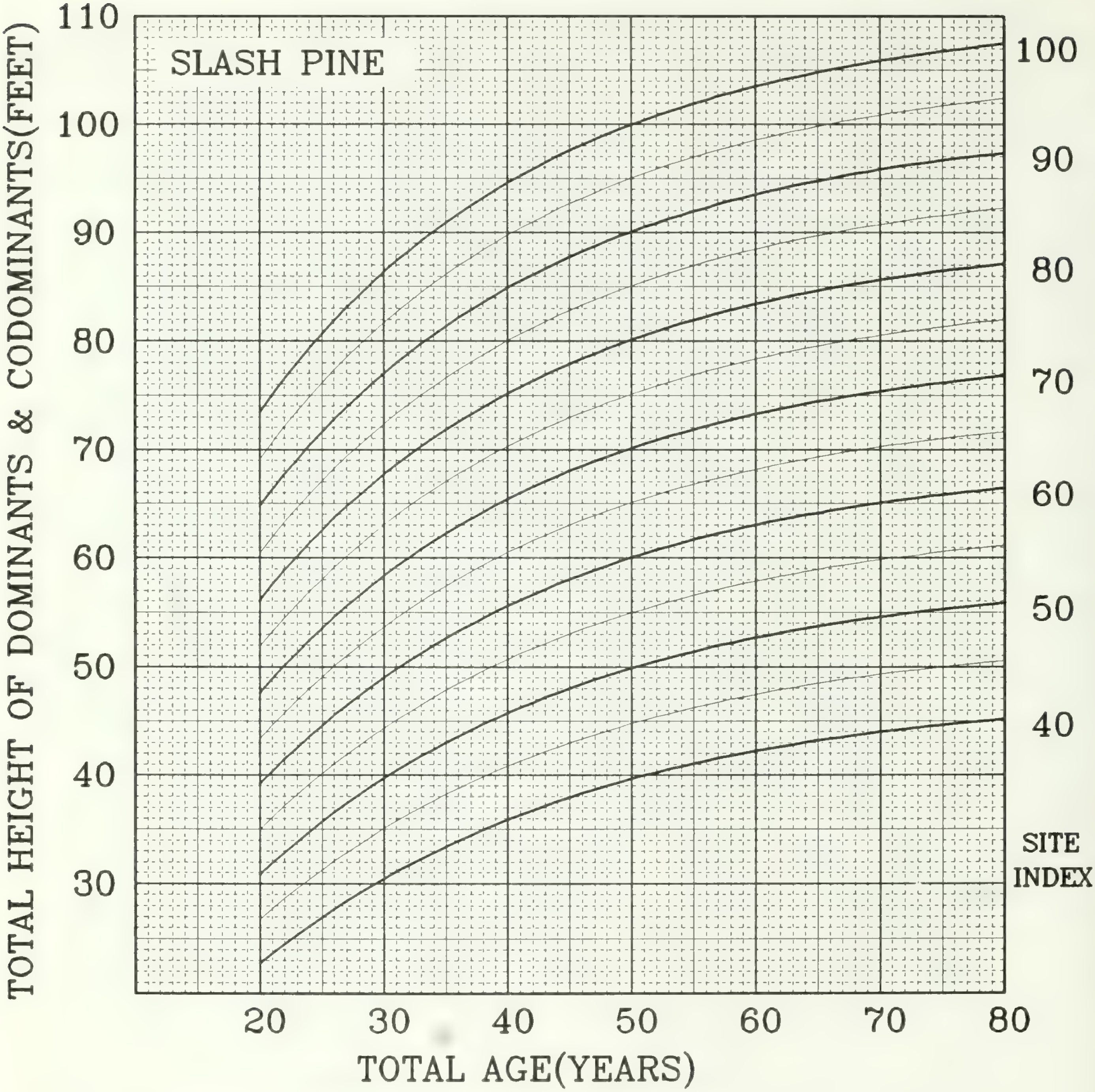

Figure 85.—Slash pine (Schumacher and Coile 1960, Coile and Schumacher 1964)
Southeastern and southern States
231 plots having 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	50-75	76+
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.6072	0.9192	-0.0390	12.9271	-0.6427	0.99	0.58	1.6
SI	0.5764	1.0893	-0.0268	-5.4782	-0.5358	0.99	0.37	1.0

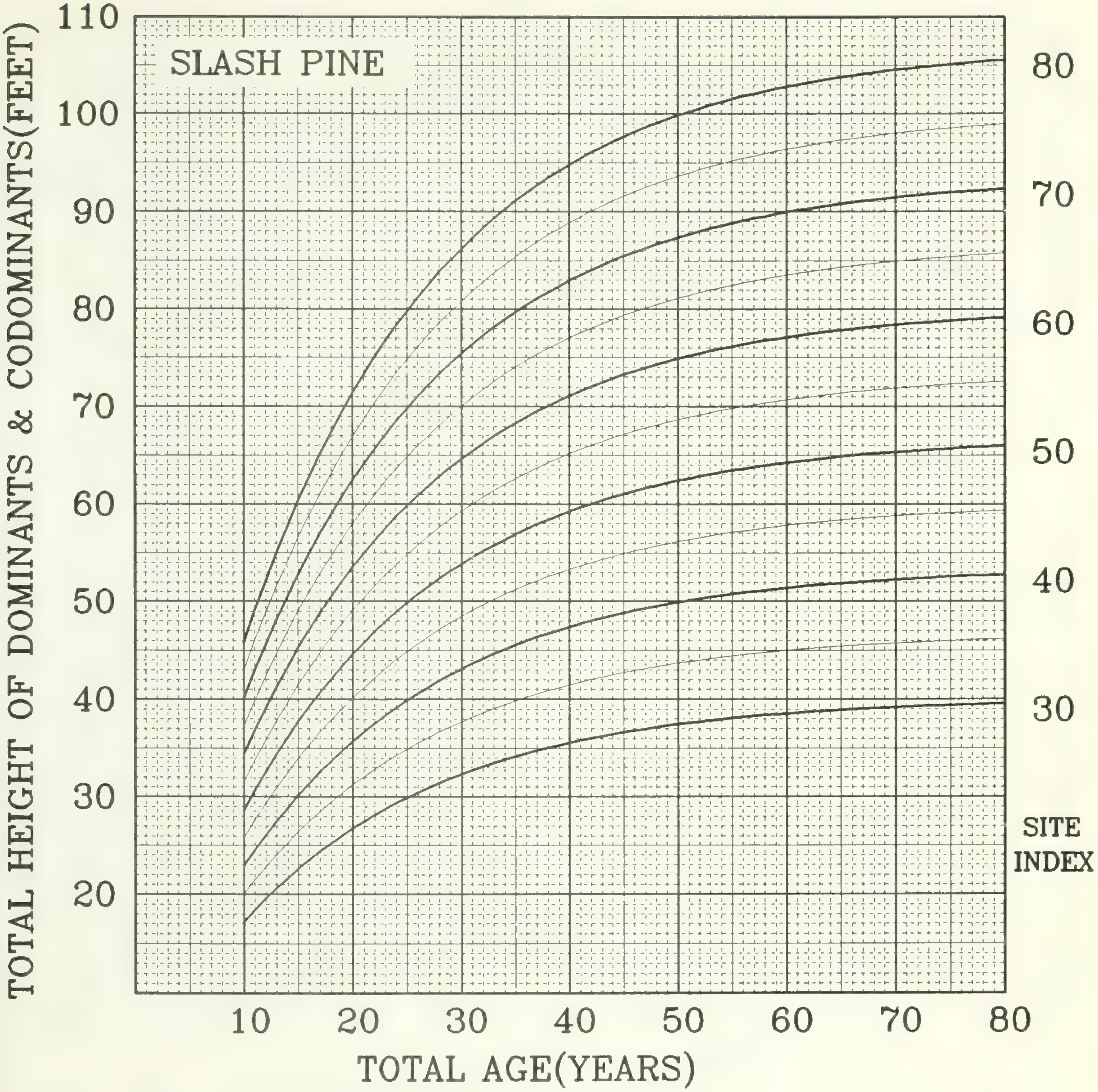

Figure 86.—Slash pine (Langdon 1959)
Florida
90 permanent growth study plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, logarithm equation
Site index is total height at 25 years total age
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<40	40-60	>60
Years:	4	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3379	0.9999	-0.0534	0.9608	-0.0001	0.99	0.88	3.6
SI	0.6874	1.0212	-0.0555	-1.3771	-0.0775	0.99	0.92	4.3

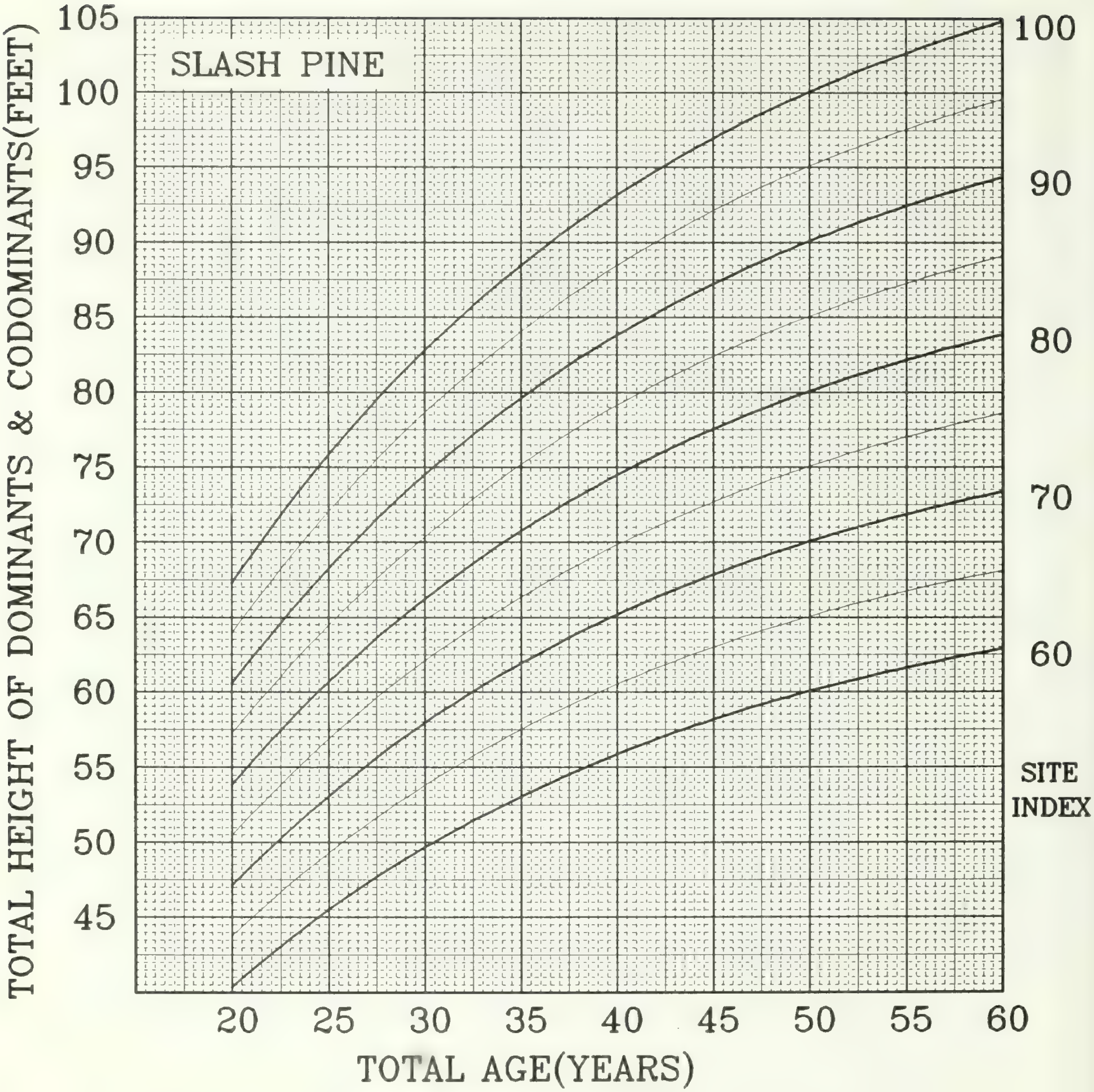

Figure 87.—Slash pine (Bennett 1970)

Florida and southern Georgia

176 permanent growth study plots, number of dominant and codominant trees not given

Total height and total age, anamorphic, logarithm equation

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	76+
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1510	1.0000	-0.0375	0.8394	0.0000	0.99	0.45	1.7
SI	0.8470	1.0062	-0.0380	-1.0187	-0.0411	0.99	0.48	2.1

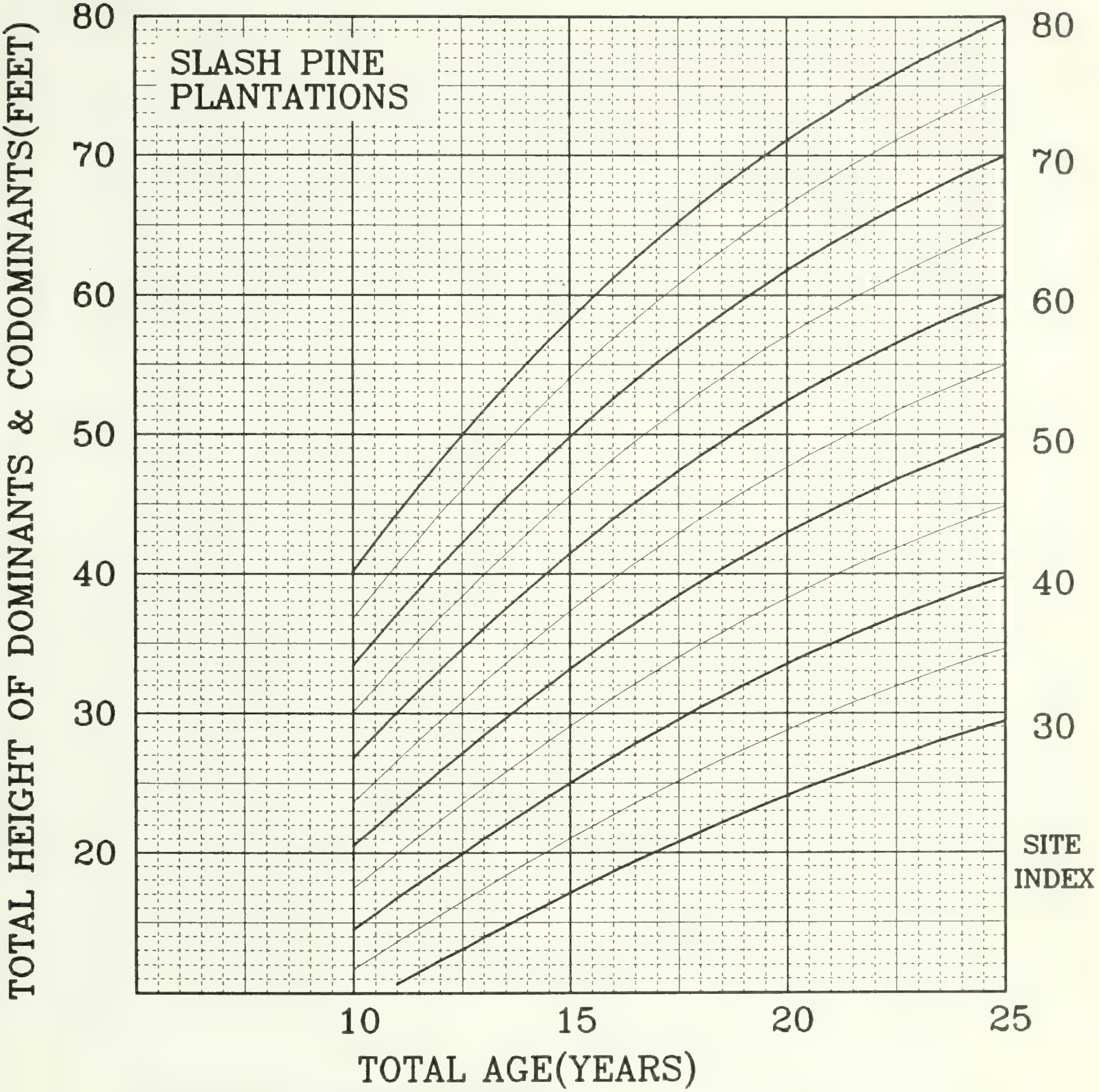

Figure 88.—Slash pine plantations (Barnes 1955)
Florida
328 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Site index is total height at 25 years total age
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<40	40-60	>60
Years:	4	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0185	0.8815	-0.0902	18.8088	-0.5520	0.99	0.91	2.0
SI	0.3372	1.1467	-0.0342	-3.4365	-0.3336	0.99	1.08	3.2

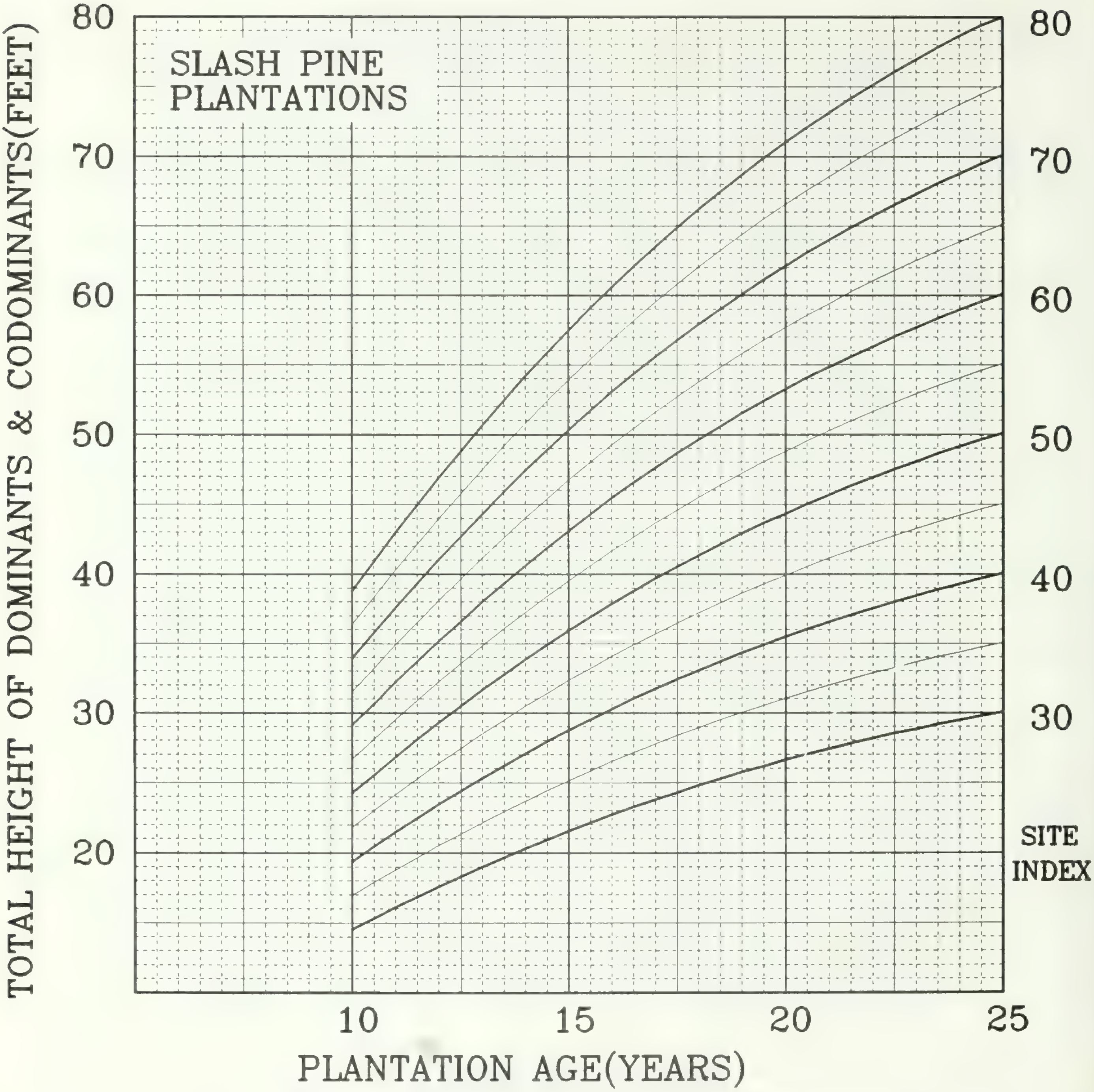

Figure 89.—Slash pine plantations (Bennett, McGee, and Clutter 1959; McGee and Bennett 1959)

Georgia middle coastal plain and Carolina sandhills

310 plots, number of dominant and codominant trees not given

Total height and total age, anamorphic, logarithm equation

Site index is total height at 25 years total age

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<40	40-60	>60
Years:	4	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2144	0.9999	-0.0916	1.7968	-0.0002	0.99	0.38	0.9
SI	0.8474	0.9983	-0.1000	-1.9954	0.0020	0.99	0.20	0.4

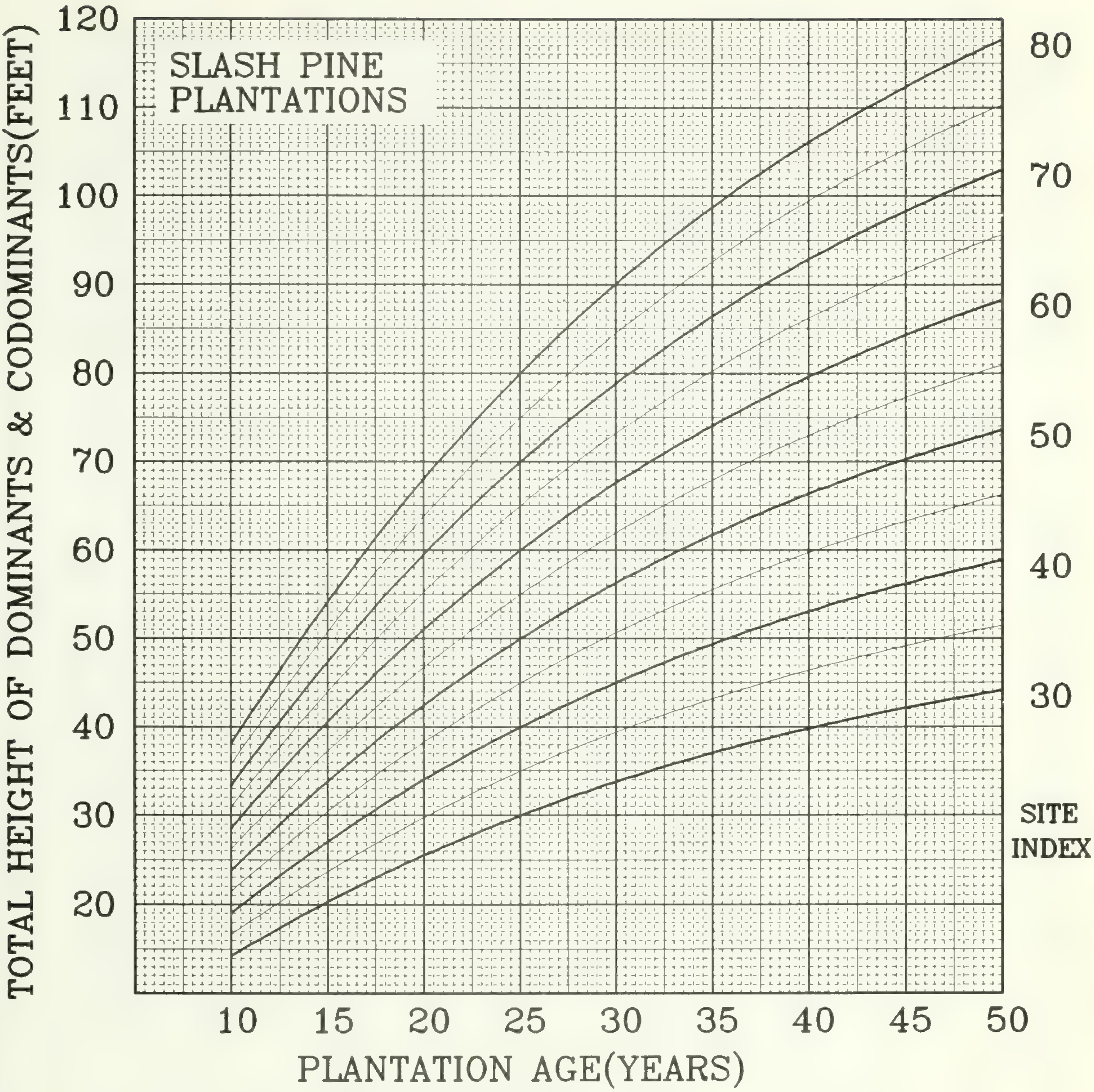

Figure 90.—Slash pine plantations (Zarnoch and Feduccia 1984)

West Gulf

247 plots, some plots remeasured, plantations mostly outside natural range of slash pine

Total height and plantation age, anamorphic, nonlinear regression

Site index is total height at plantation age of 25 years

Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	<55	>55
Years:	2	1

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.8395	1.0001	-0.0335	1.0774	0.0001	0.98	0.72	1.4
SI	0.5135	1.0169	-0.0348	-1.2309	-0.0278	0.98	0.79	1.9

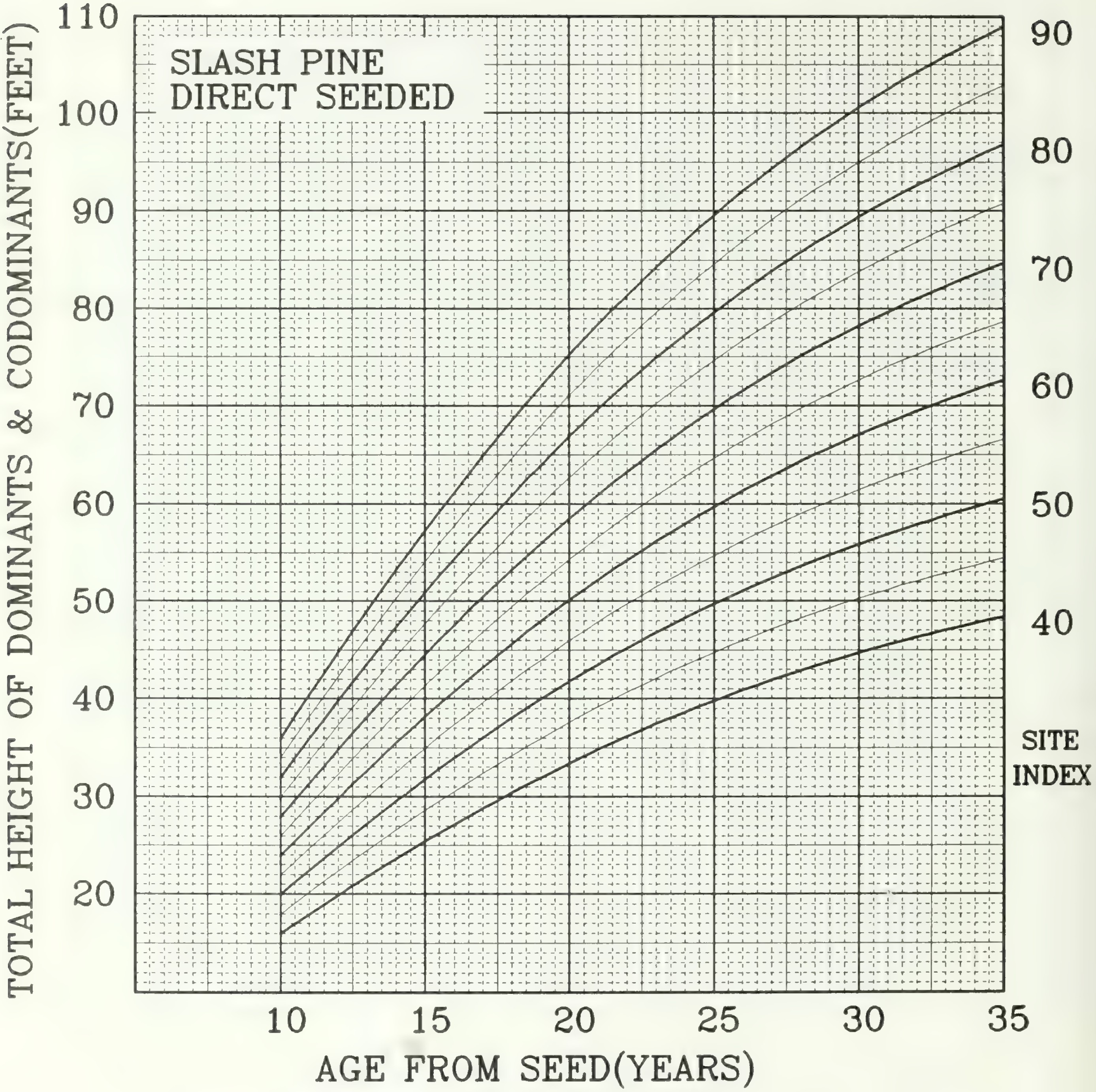

Figure 91.—Slash pine direct-seeded (Lohrey 1987)

Louisiana

218 plots in cutover forest sites that were site prepared and direct seeded; remeasurements from most plots

Total height and age from seed from 10 or more dominant and codominant trees on each plot, anamorphic, logarithm equation

Site index is total height at 25 years age from seed

Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	<55	>55
Years:	2	1

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4698	0.9998	-0.0645	1.7575	0.0009	0.99	1.17	1.3
SI	0.6687	1.0058	-0.0655	-2.0012	-0.0294	0.99	1.10	1.6

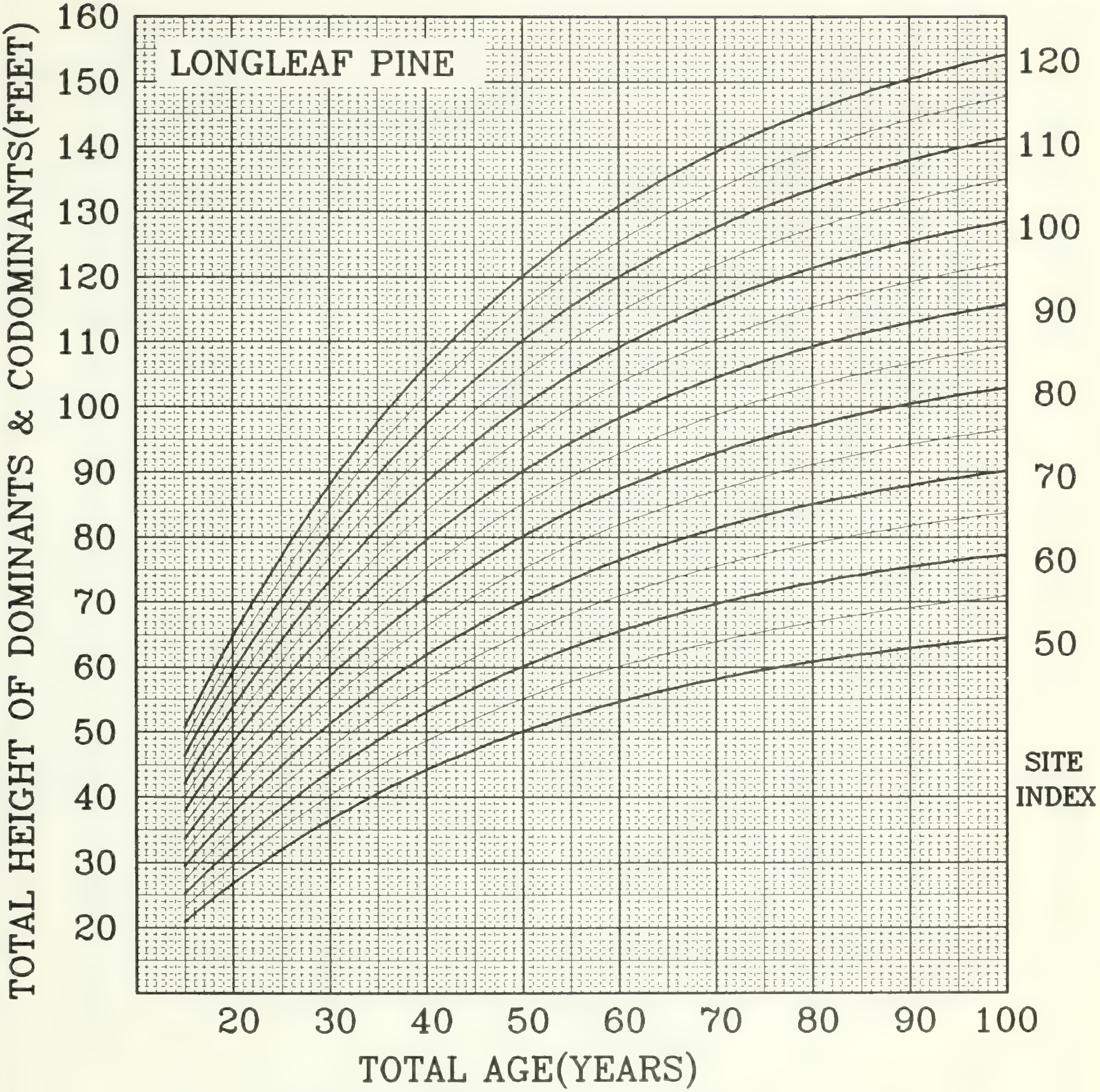

Figure 92.—Longleaf pine (USDA 1929)
Southern States
244 plots, number of dominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40	50	60	65-95	96+
Years:	10	8	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4210	0.9947	-0.0269	1.1344	-0.0109	0.99	1.19	5.5
SI	0.6333	1.0310	-0.0278	-1.6207	-0.0878	0.99	1.36	7.3

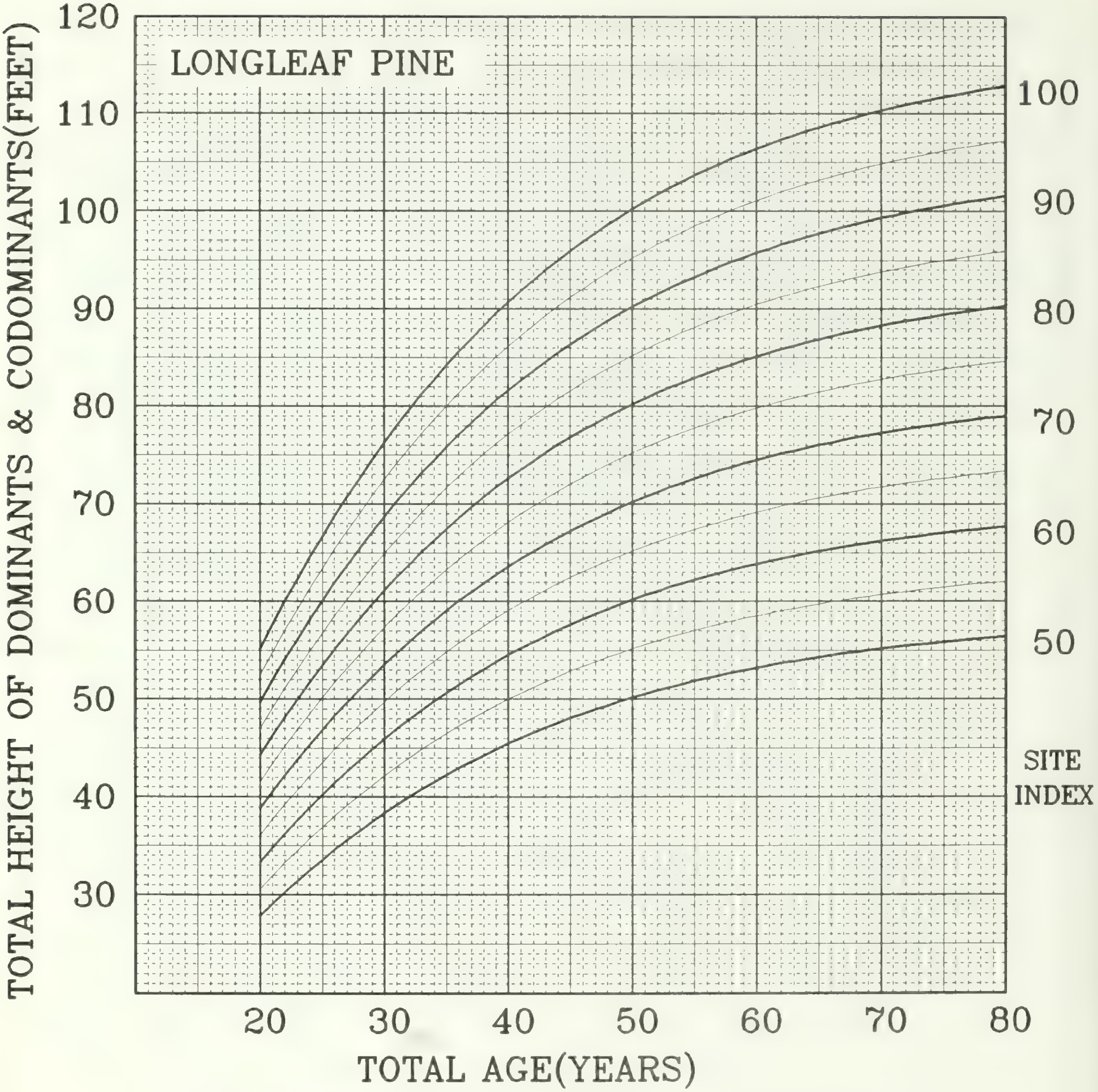

Figure 93.—Longleaf pine (Schumacher and Coile 1960)
Atlantic Coastal Plain
368 plots having 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	50	60	65-95	96+
Years:	8	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1672	1.0010	-0.0459	1.3460	0.0204	0.99	1.15	3.2
SI	0.7948	1.0171	-0.0470	-2.1964	-0.0864	0.99	1.15	4.2

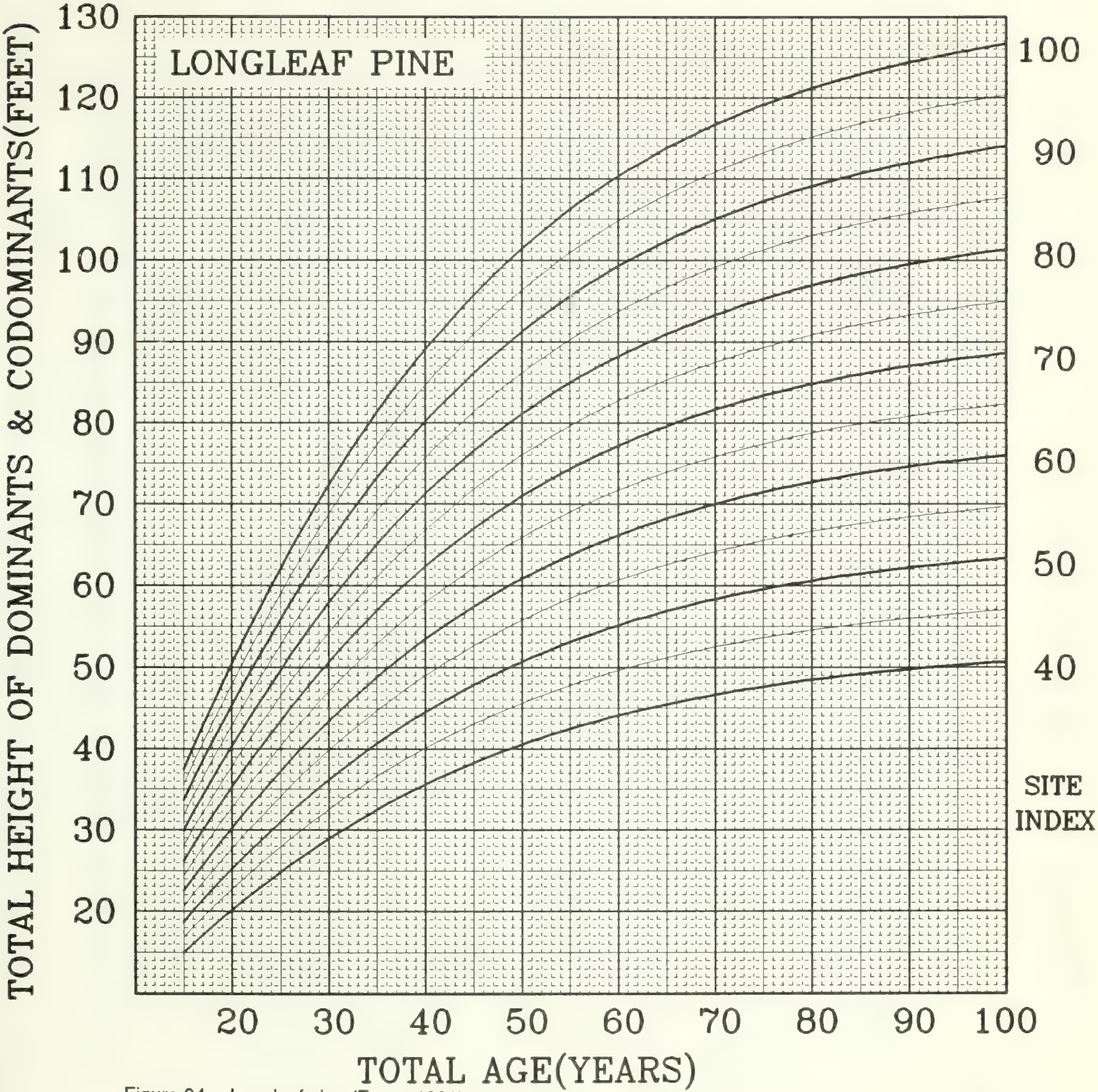

Figure 94.—Longleaf pine (Farrar 1981)

Coastal plain of Northwest Florida, Southwest Georgia, South and Central Alabama, and South Mississippi

182 permanent growth study plots on naturally regenerated lands, remeasurements of total height and age from dominant and codominant trees

Weighted multiple linear regression, anamorphic

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40	50	60	65-95	96+
Years:	10	8	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.3196	1.0000	-0.0356	1.4271	0.000017	0.99	3.43	8.6
SI	0.6398	1.0401	-0.0345	-2.6970	-0.1749	0.99	3.78	8.3

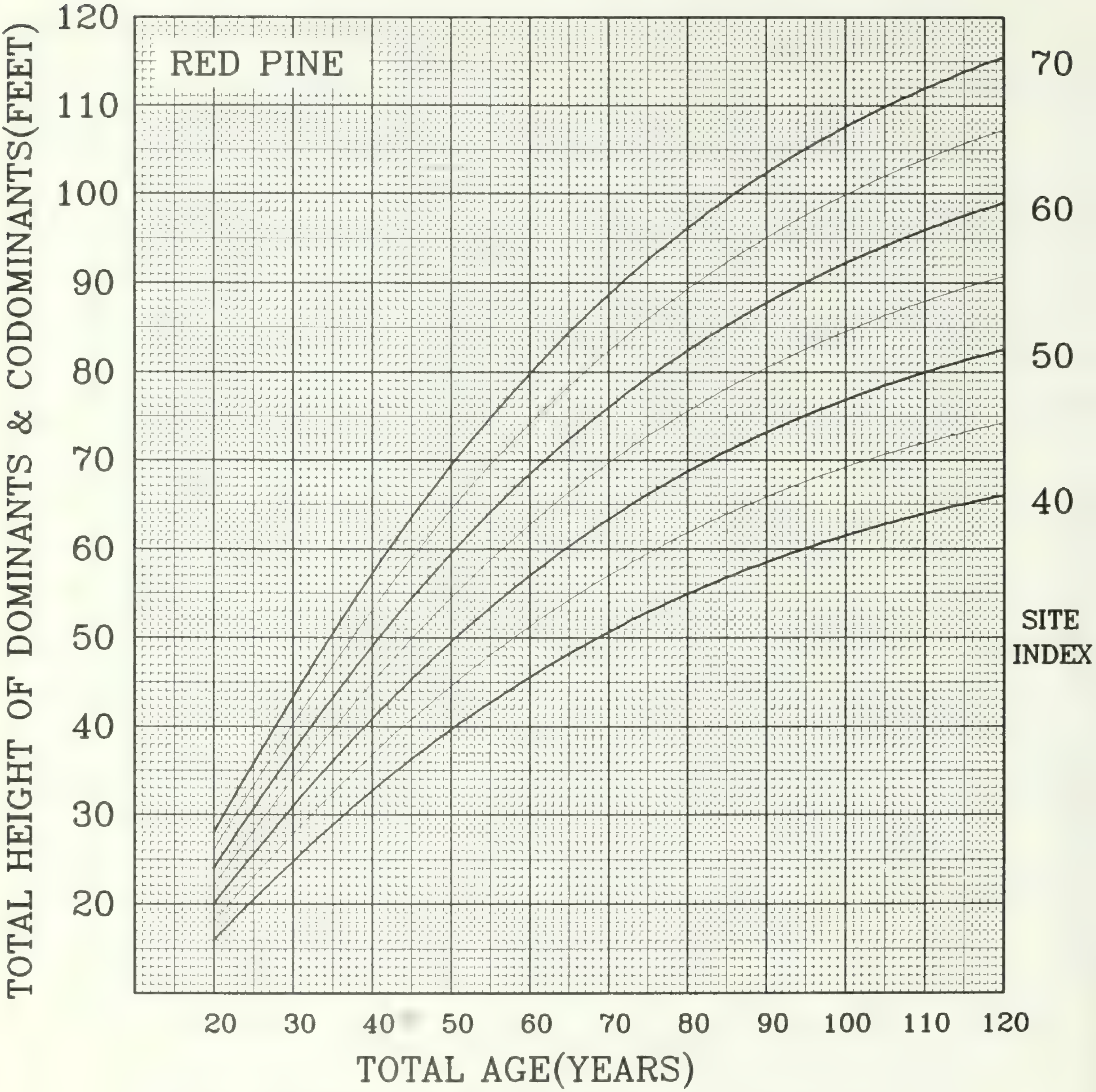

Figure 95.—Red pine (Gevorkiantz 1957c, derived from Eyre and Zehngraff 1948, and Brown and Gevorkiantz 1934)

Minnesota

Number of plots and number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40	50	60	70+
Years:	8	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.8900	1.0000	-0.0198	1.3892	0.0000	0.99	0.64	1.4
SI	0.5291	1.0000	-0.0198	-1.3892	0.0000	0.99	0.64	1.4

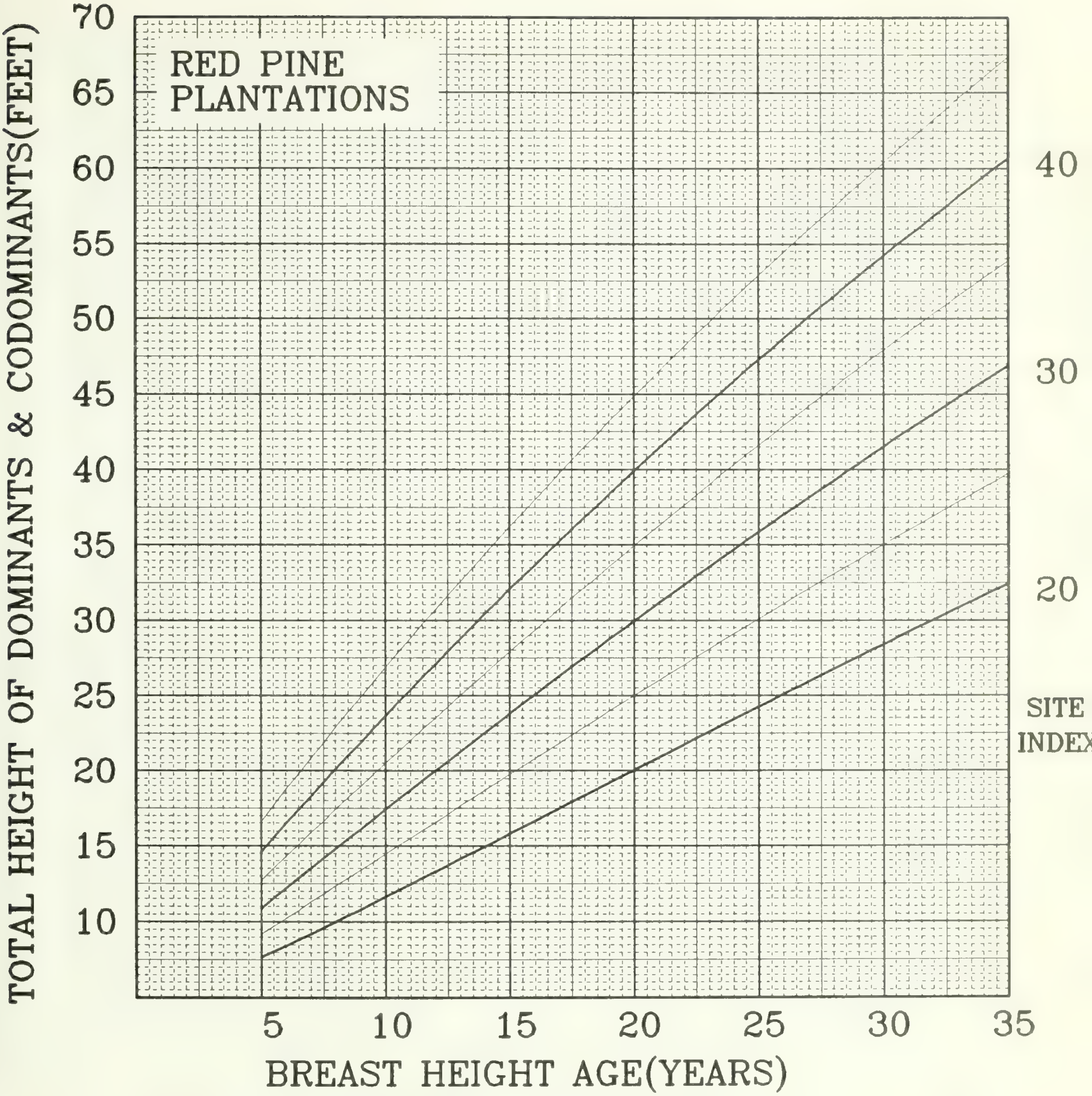

Figure 96.—Red pine plantations (Richards, Morrow, and Stone 1962)
New York
96 plots having 6 to 10 dominant and codominant trees on each plot
Total height and breast height age, polymorphic, independent curves plotted for each site class
Site index is height at 20 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	19.0635	0.5885	-0.0111	3.3922	-0.3418	0.95	0.76	1.1
SI	0.0199	1.0192	-0.0081	-0.7730	0.0424	0.97	1.09	1.9

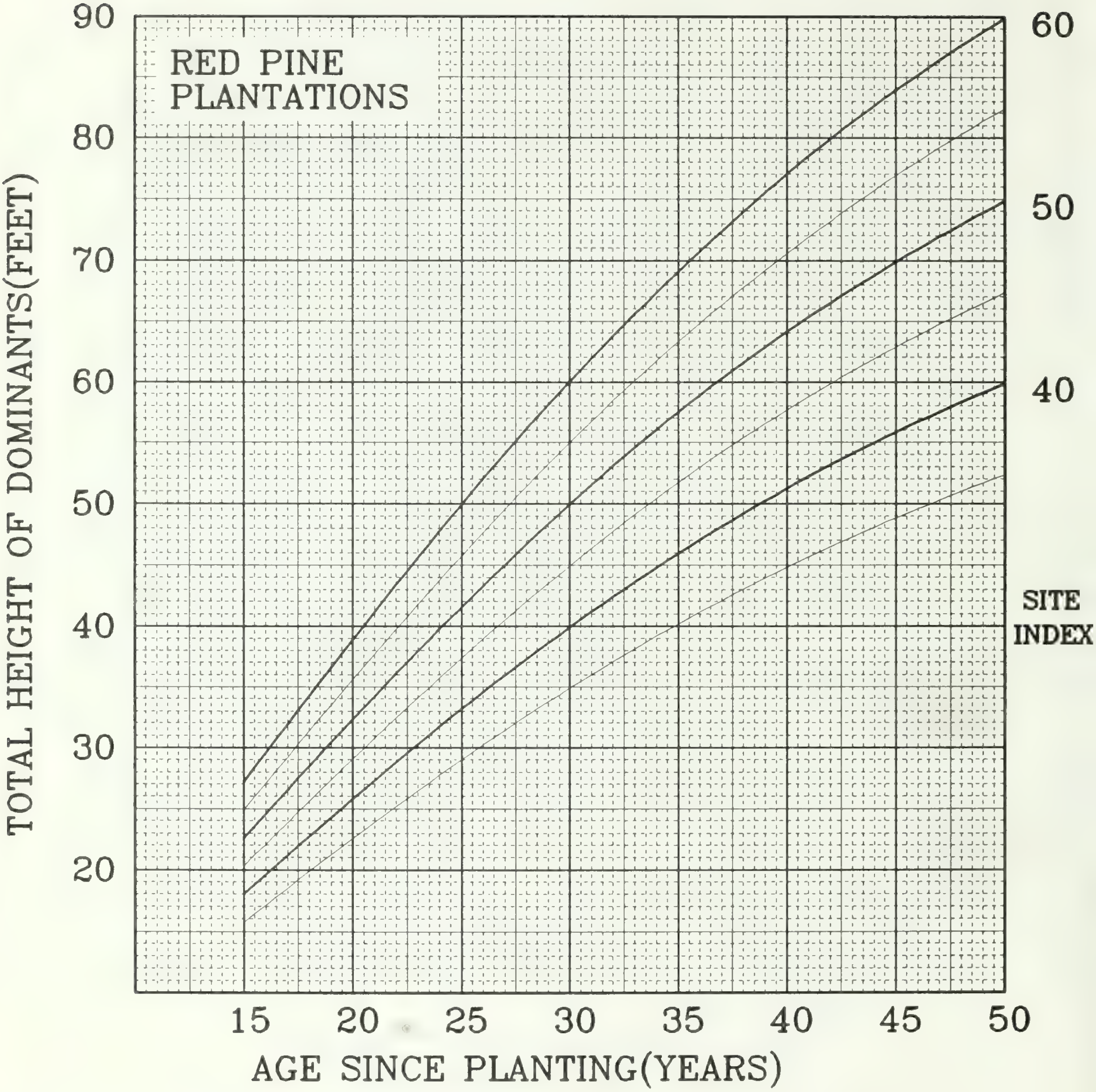

Figure 97.—Red pine plantations (Hannah 1971)
Vermont
92 plots having 2 to 4 dominant trees on each plot
Total height and plantation age, anamorphic, logarithm equation
Site index is total height at 30 years plantation age
Add 7 years to d.b.h. age to obtain plantation age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0401	1.0003	0.0361	1.7914	-0.0090	0.94	0.62	0.4
SI	0.4935	0.9966	-0.0353	-1.7278	-0.0051	0.95	0.65	0.6

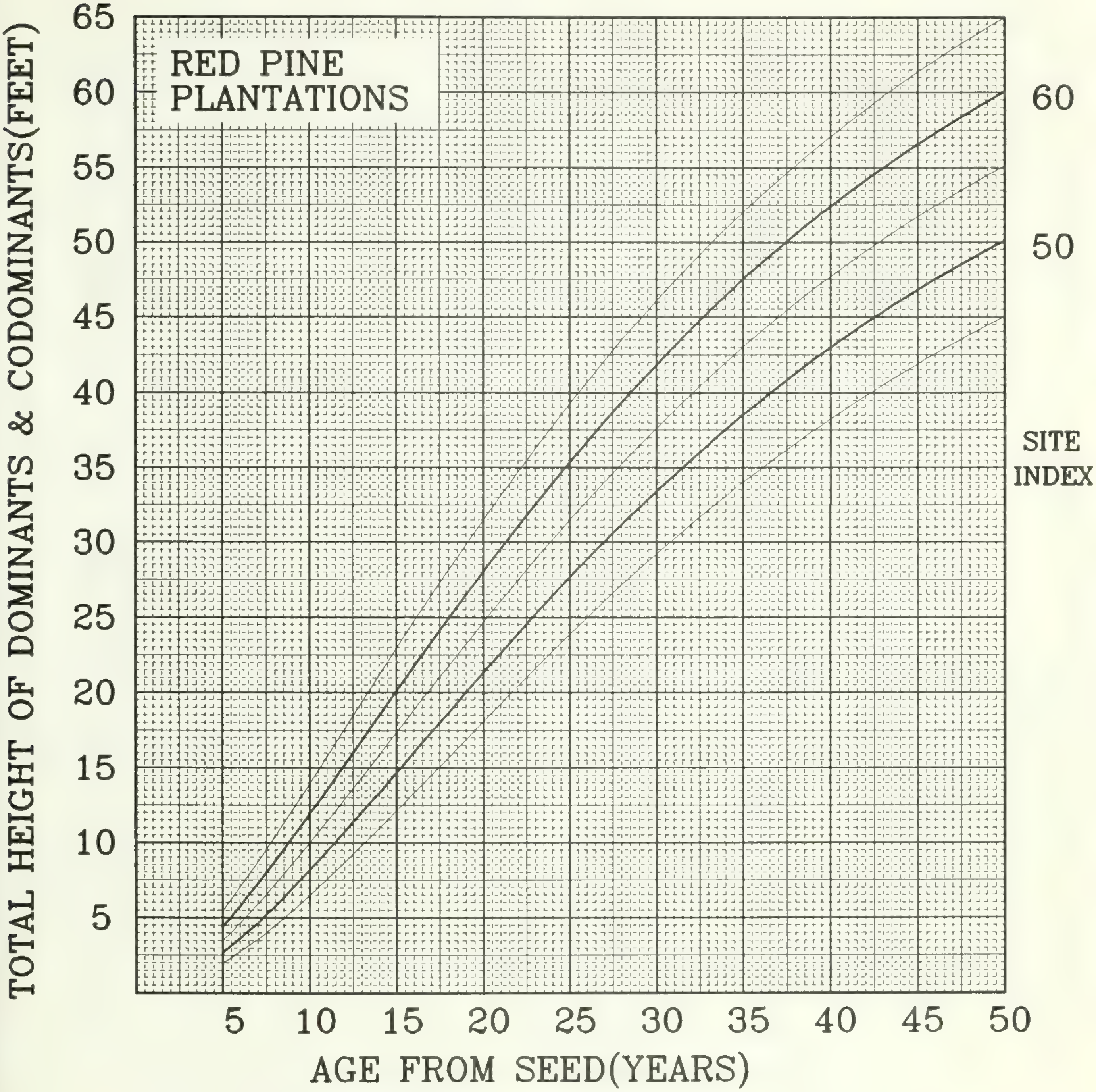

Figure 98.—Red pine plantations (Wilde *et al.* 1965)
Wisconsin
69 plantations, number of dominant and codominant trees not given
Total height and age from seed, anamorphic, equation not given
Add 7 years to d.b.h. age to obtain age from seed (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.6359	0.8259	-0.0389	21.5578	-0.6271	0.98	1.05	1.6
SI	0.0102	1.4990	-0.0004	-1.4930	-0.2058	0.99	1.62	4.0

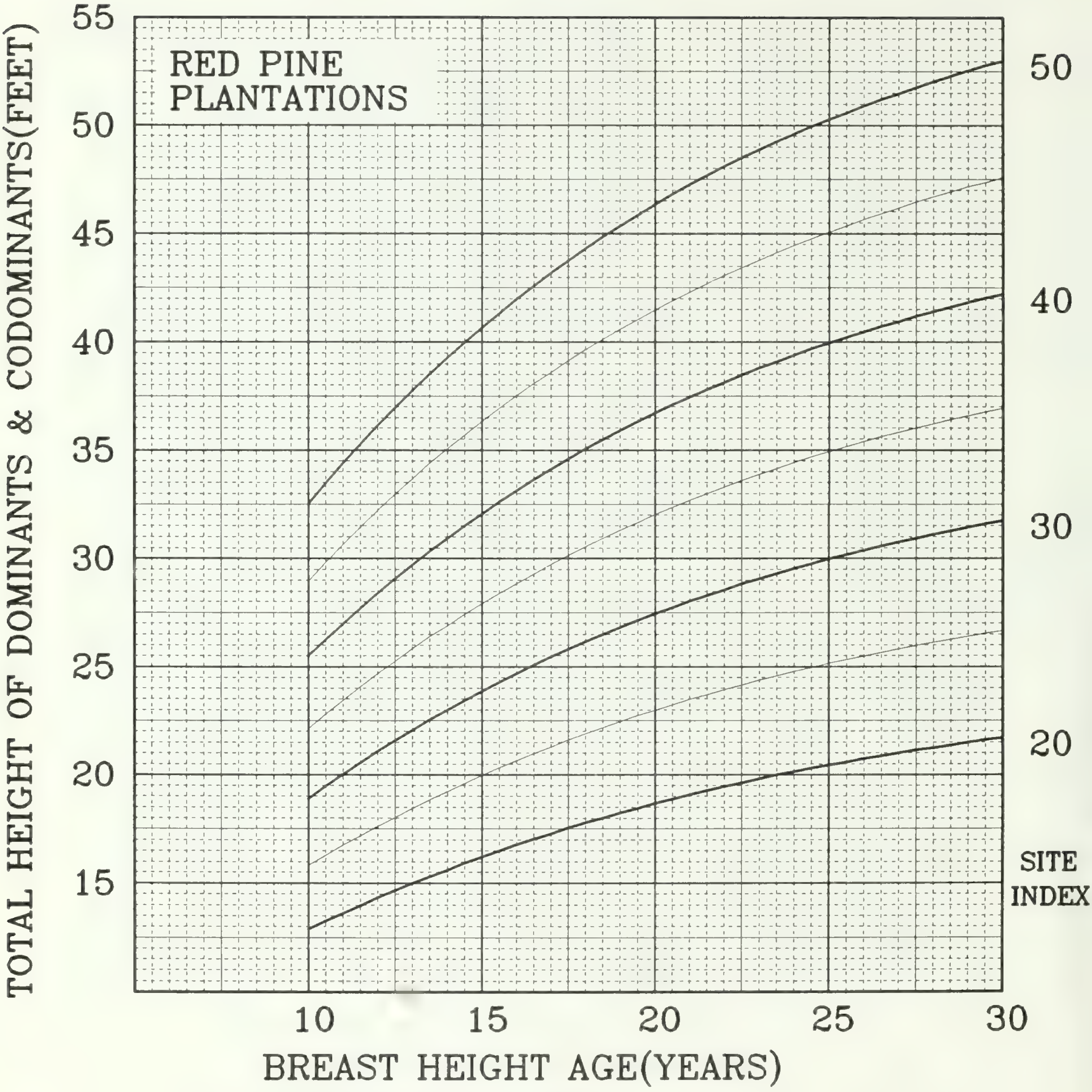

Figure 99.—Red pine plantations (Gilmore 1967)
Illinois
60 plantations, number of dominant trees not given
Total height and breast height age, anamorphic, logarithm equation
Site index is total height at 25 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.7666	1.0909	-0.0733	3.2335	-0.2947	0.98	1.17	1.2
SI	0.3862	1.1649	-0.0646	-1.0878	-0.0287	0.97	1.08	1.0

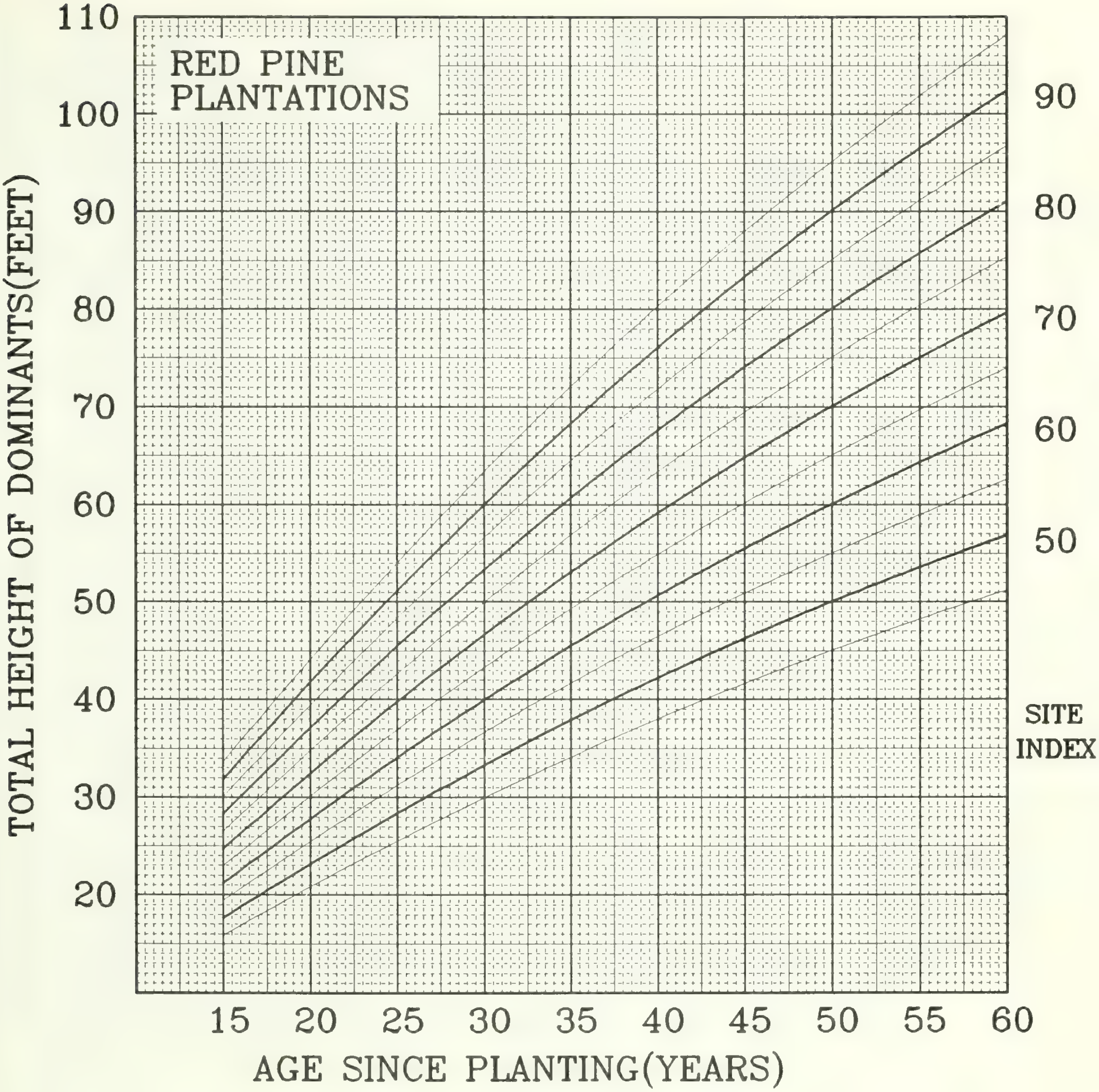

Figure 100.—Red pine plantations (Stiell and Berry 1973b, Berry 1984)
Eastern Ontario—Petawawa
31 plantations having 56 permanent growth study plots
Periodic height measurements, anamorphic, quadratic equation not given
Site index is total height at 50 years since planting
Add 5 years to d.b.h. age to obtain years since planting (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.0434	0.9978	-0.0147	1.0937	-0.0035	0.89	0.44	0.4
SI	0.4950	0.9965	-0.0143	-1.0491	0.0039	0.92	0.51	0.5

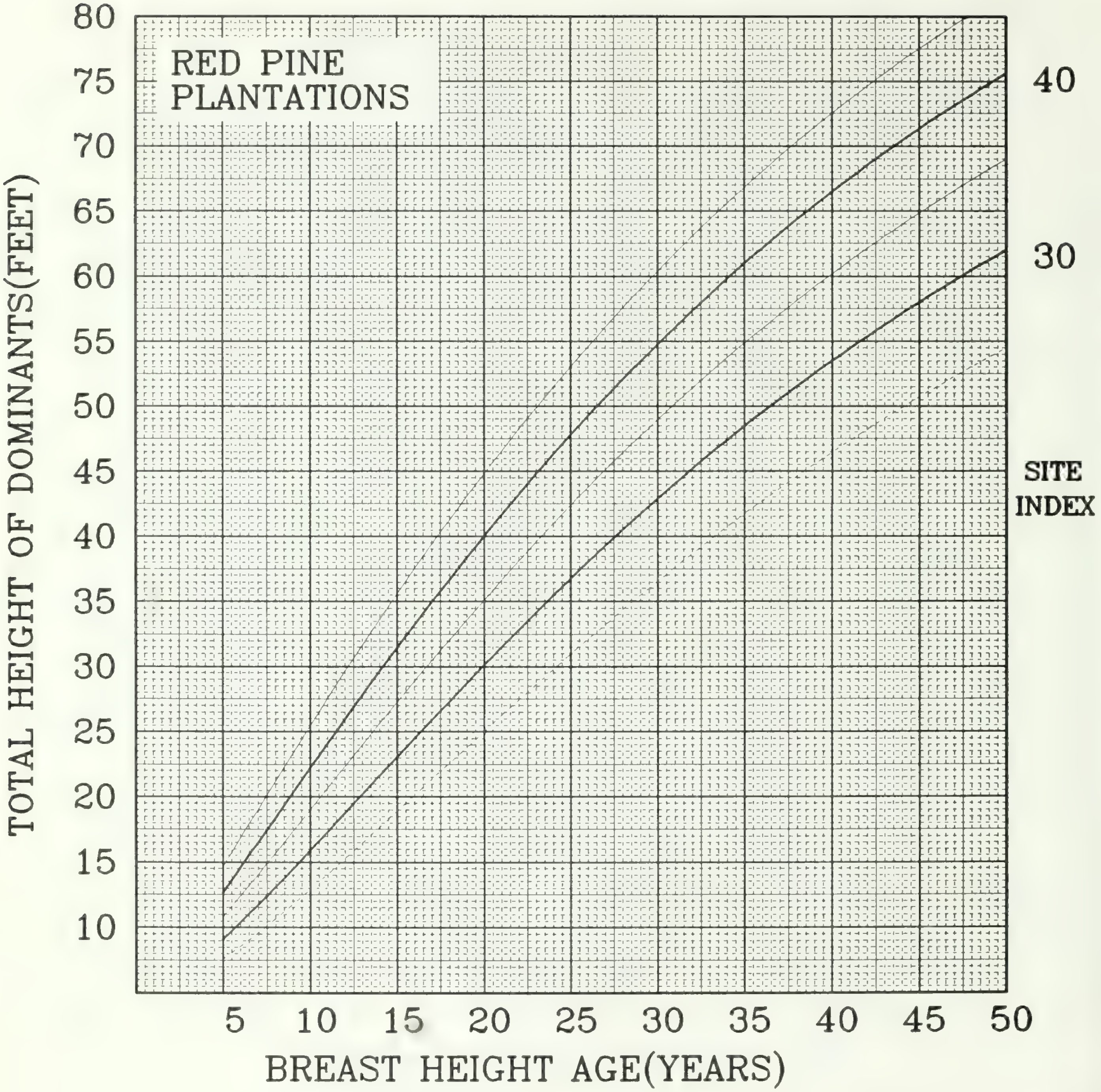

Figure 101.—Red pine plantations (Thrower 1986b)

North central Ontario

25 plots having 3 dominant trees per plot

Internode measurements and stem analysis, nonlinear regression, polymorphic

Site index is total height at 20 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	13.6713	0.5404	-0.0283	8.7720	-0.5308	0.94	0.55	0.5
SI	0.00098	1.4784	-0.00023	-1.1602	-0.0574	0.99	1.35	3.7

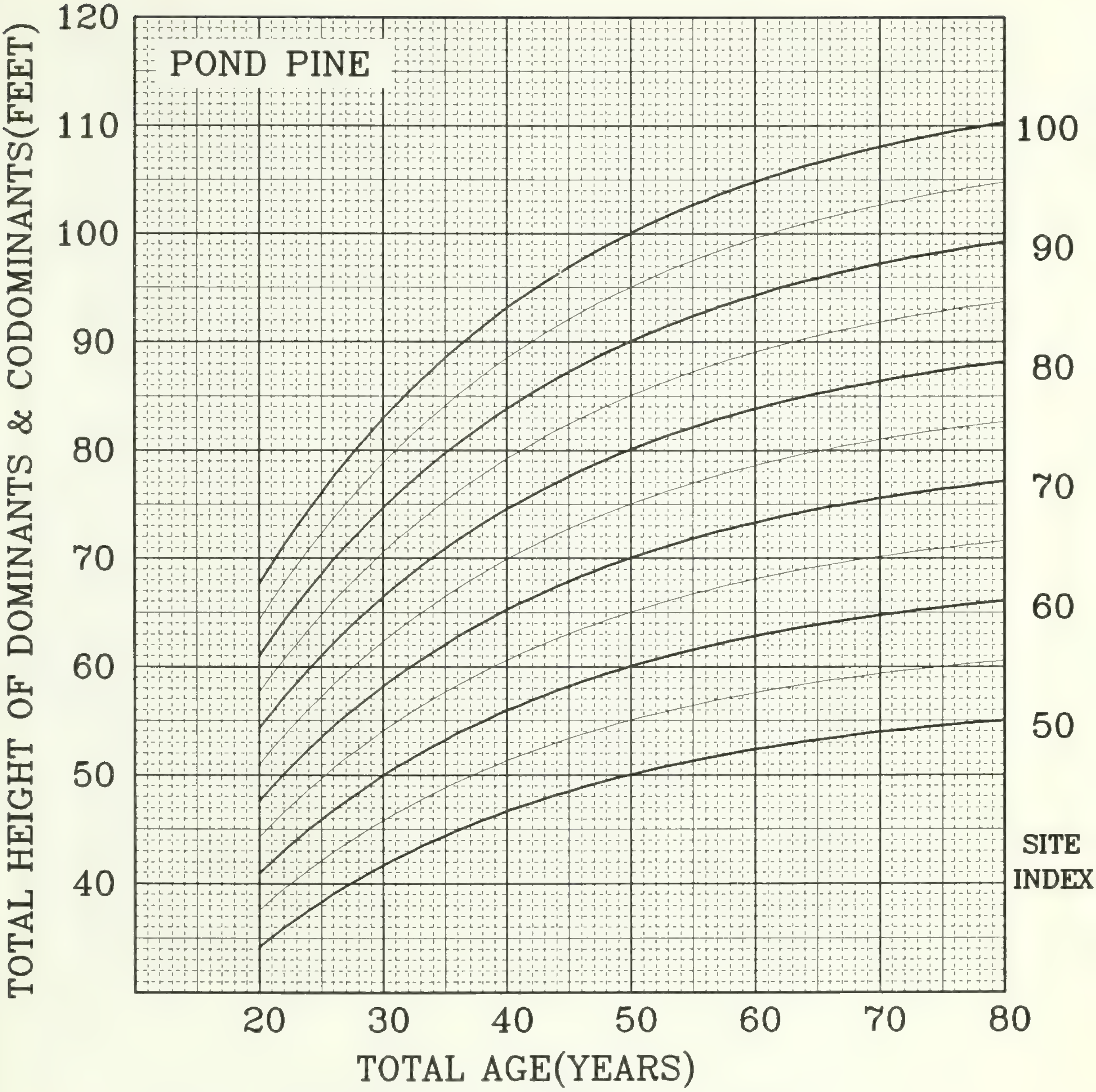

Figure 102.—Pond pine (Schumacher and Coile 1960)
Coastal Plain of North Carolina, South Carolina, and Georgia
130 plots having 8 dominant and codominant trees on each plot
Total height and age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	50-75	75-100
Years:	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1266	1.0051	-0.0367	0.6780	0.0404	0.99	0.61	1.6
SI	0.8682	1.0012	-0.0384	-0.8561	-0.0016	0.99	0.68	2.1

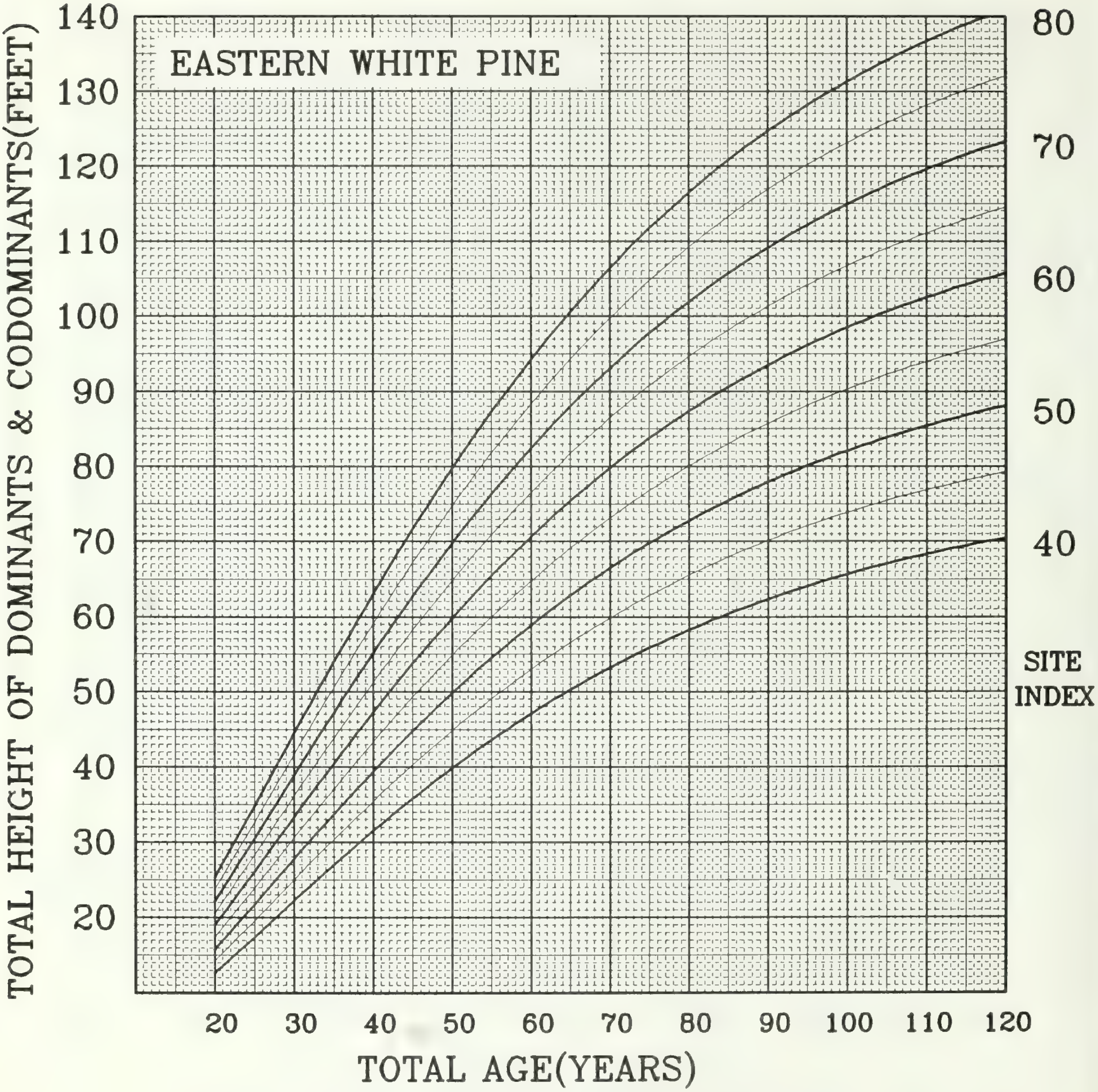

Figure 103.—Eastern white pine (Gevorkiantz 1957f, derived from Gevorkiantz and Zon 1930)

Northern Wisconsin

92 plots, number of dominant and codominant trees not given

Total height and total age, anamorphic, equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	40	50	60	70	80
Years:	12	12	10	8	6

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.9660	1.0000	-0.0240	1.8942	0.0000	0.99	0.66	1.7
SI	0.5086	1.0000	-0.0240	-1.8942	0.0000	0.99	0.66	1.7

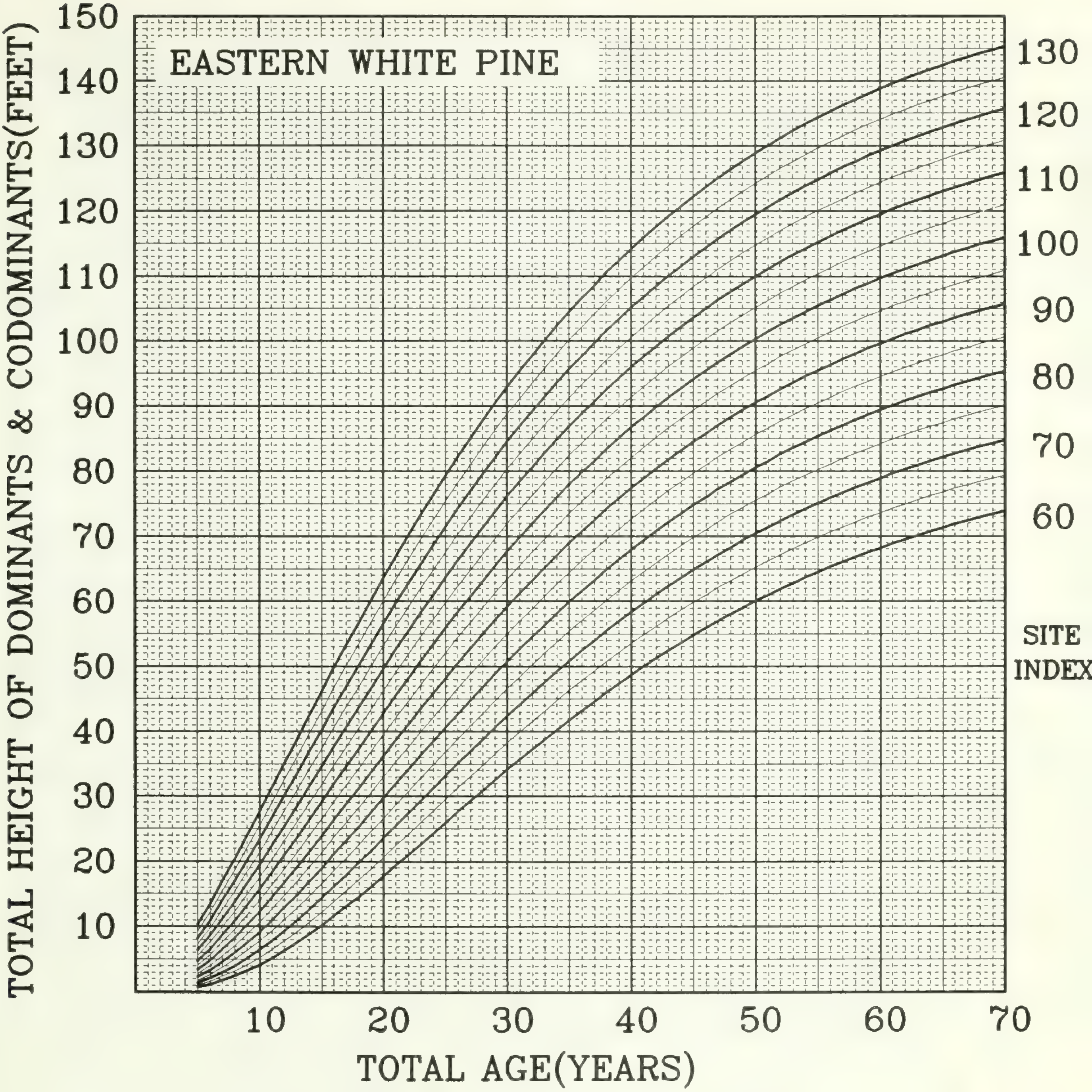

Figure 104.—Eastern white pine (Beck 1971a, 1971b)

Appalachian Mountains of Virginia, Tennessee, North Carolina, and Georgia

42 plots having 3 dominant and codominant trees on each plot

Stem analysis, polymorphic, nonlinear regression

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	50-65	66-80	81-95	96-110	111+
Years:	7	6	5	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	3.2425	0.7980	-0.0435	52.0549	-0.7064	0.99	2.24	2.8
SI	0.4732	1.0520	-0.0168	-2.2944	-0.1984	0.99	3.95	9.6

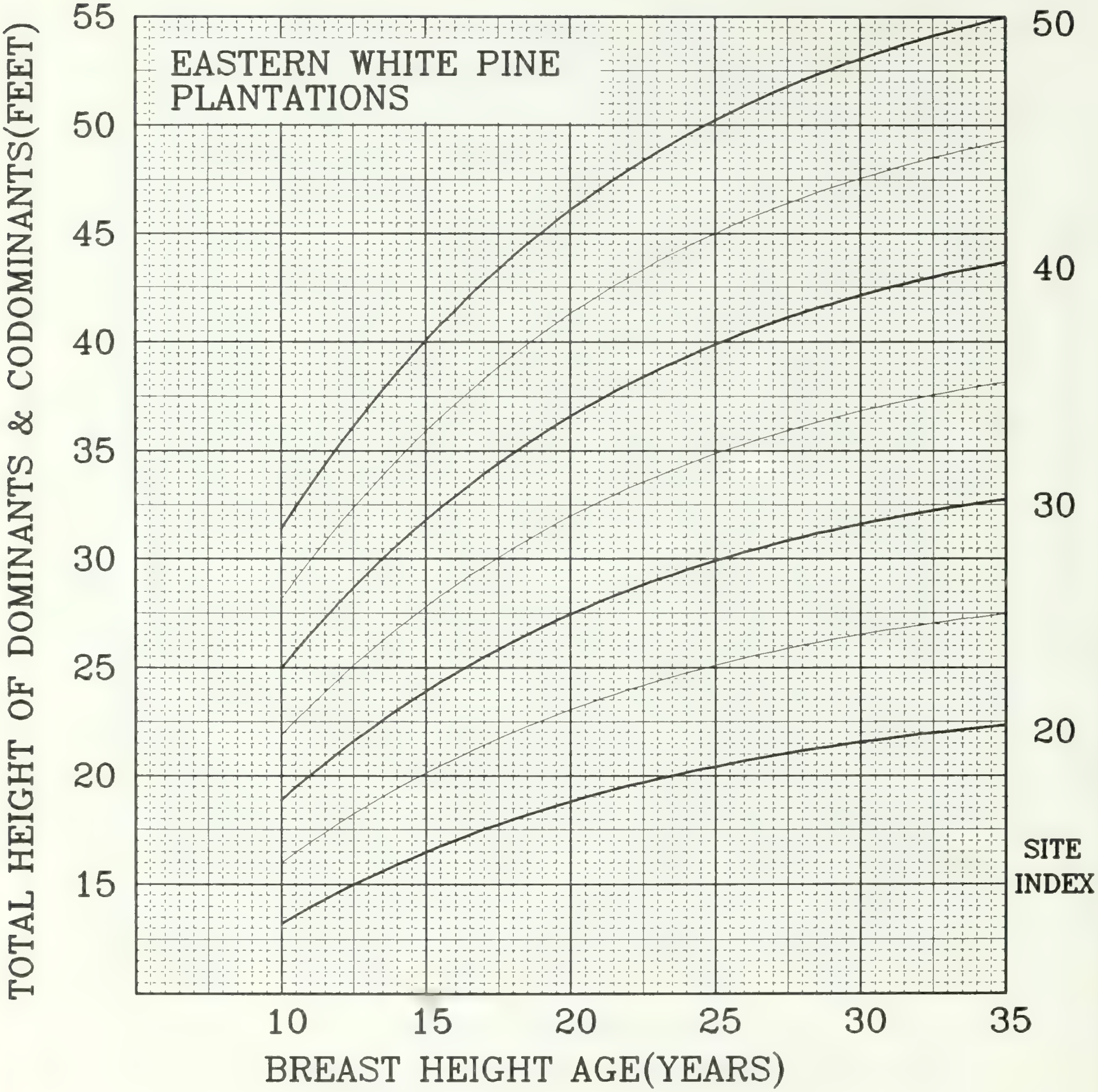

Figure 105.—Eastern white pine plantations (Gilmore 1968)
Illinois
48 plantations, number of dominant trees not given
Total height and breast height age, anamorphic, logarithm equation
Site index is height at 25 years breast height age (BH = 4.5)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.6689	1.1249	-0.0785	1.9792	-0.1365	0.97	0.97	1.0
SI	0.4143	1.1539	-0.0771	-1.0397	0.0379	0.97	0.96	1.2

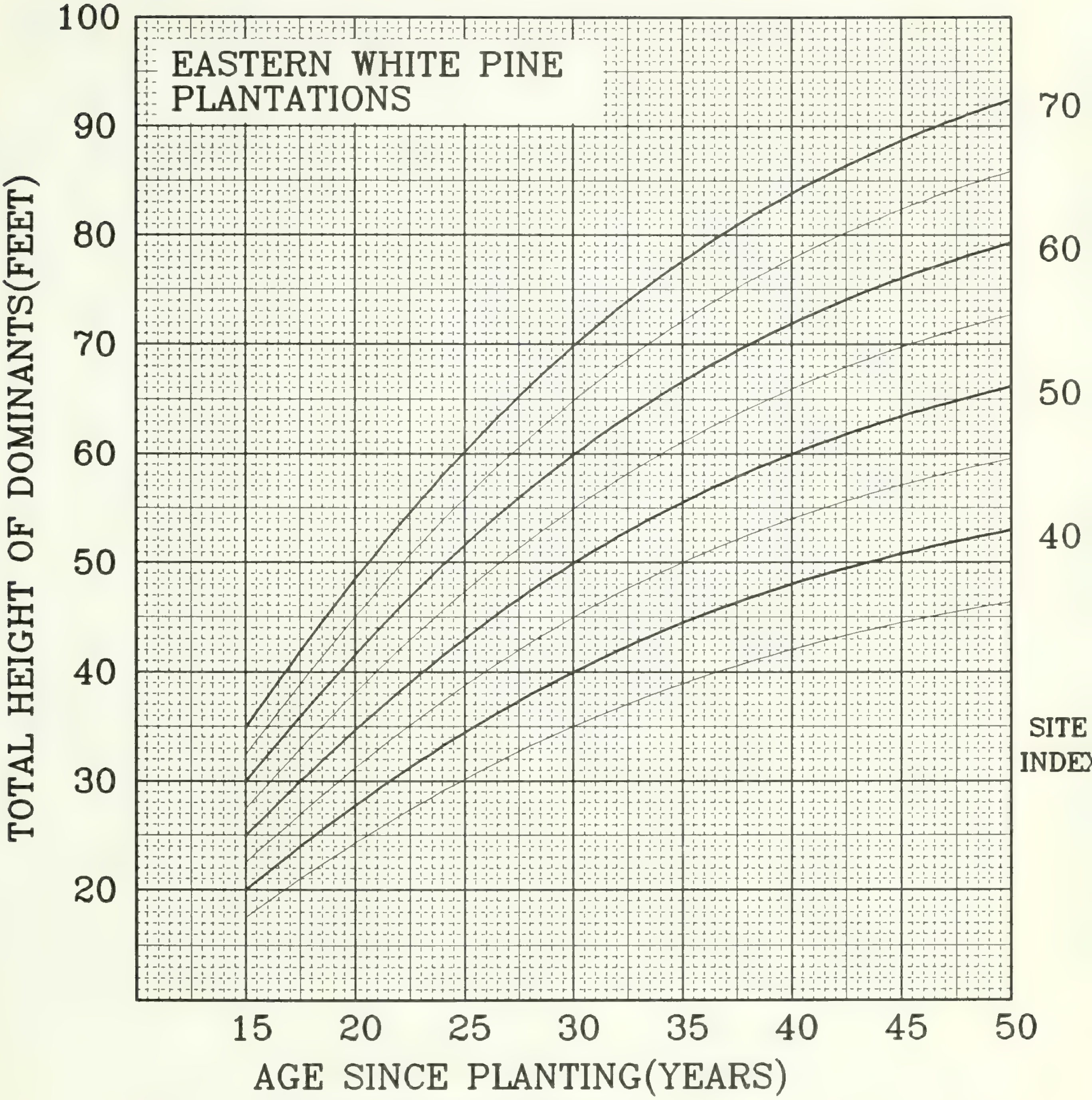

Figure 106.—Eastern white pine plantations (Hannah 1971)
Vermont
75 plots having 2 to 4 dominant trees on each plot
Total height and plantation age, anamorphic, logarithm equation
Site index is total height at 30 years plantation age
Add 9 years to d.b.h. age to obtain plantation age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5269	0.9955	-0.0550	1.9118	0.00048	0.98	0.89	1.6
SI	0.6457	1.0096	-0.0564	-2.0691	-0.0119	0.98	0.86	1.5

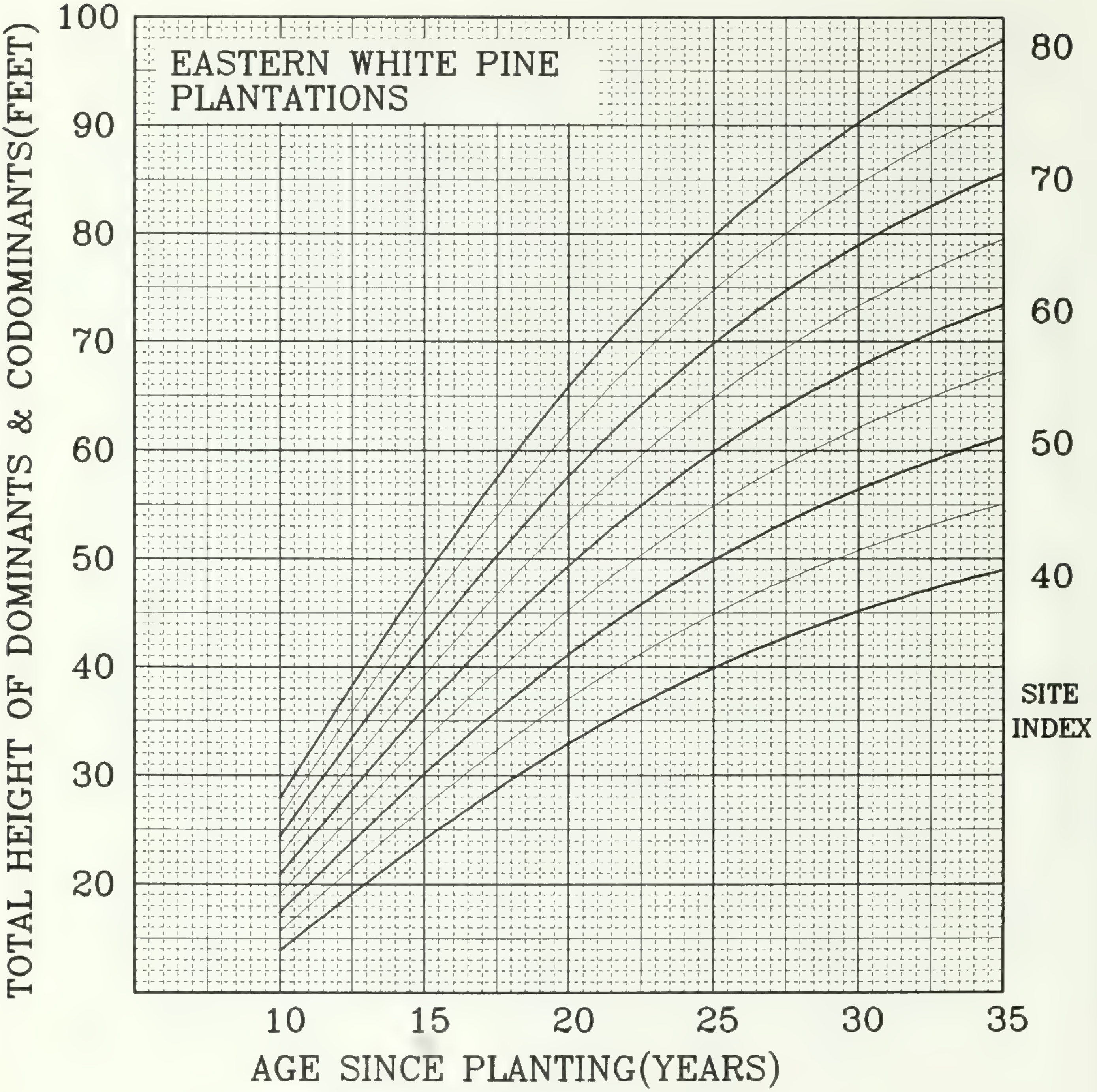

Figure 107.—Eastern white pine plantations (Vimmerstedt 1959, 1962)
Southern Appalachian Mountains of North Carolina, Tennessee, and Georgia
111 plots having 5 to 6 dominant and codominant trees on each plot
Total height and age, anamorphic, logarithm equation
Site index is total height at 25 years plantation age
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	50-65	66-80	81-95	96+
Years:	7	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.4638	0.9979	-0.0743	2.2460	-0.0040	0.99	0.51	0.9
SI	0.6590	1.0117	-0.0744	-2.5813	-0.0423	0.99	0.60	1.3

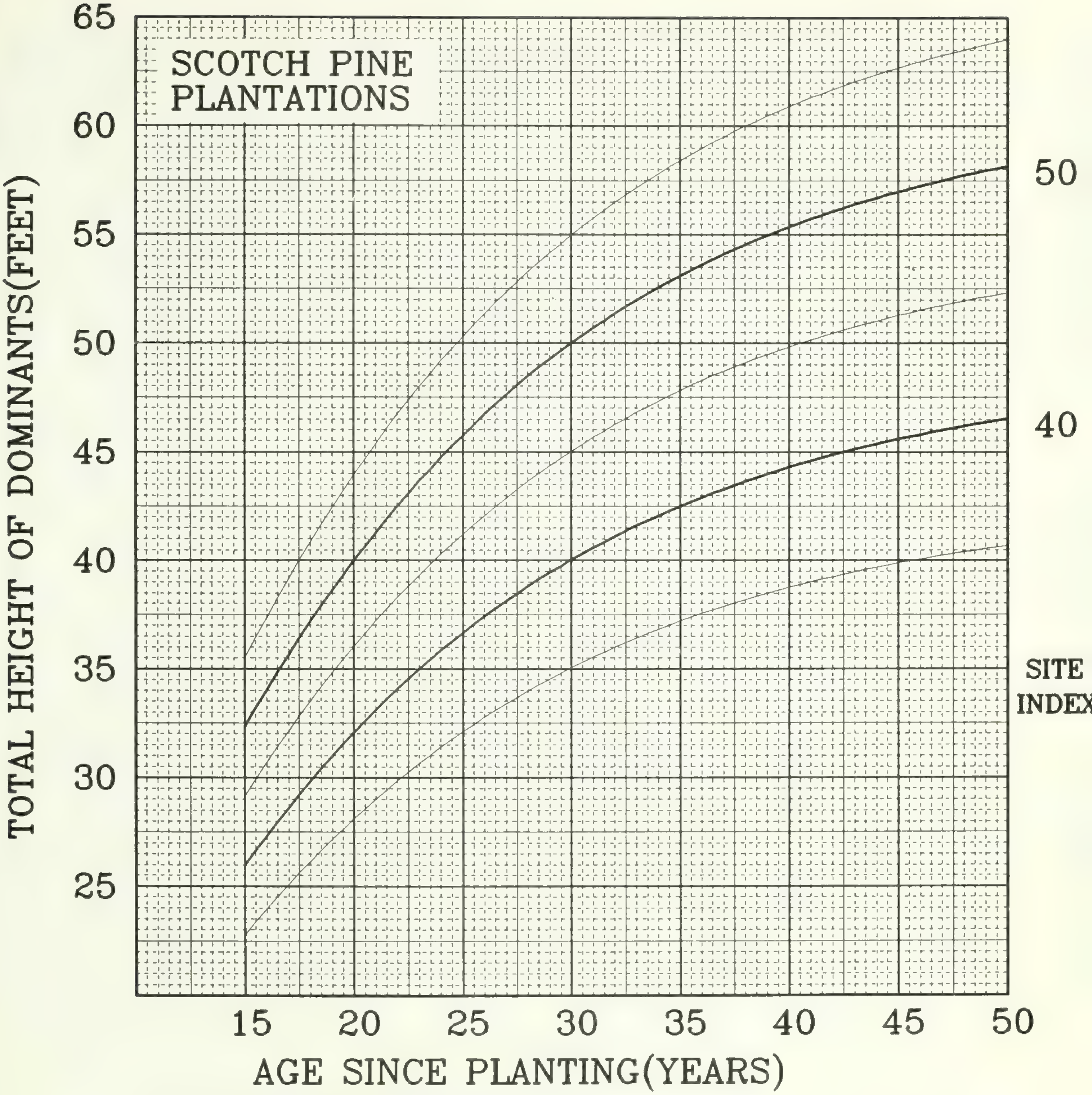

Figure 108.—Scotch pine plantations (Hannah 1971)
Vermont
31 plots having 2 to 4 dominant trees on each plot
Total height and plantation age, anamorphic, logarithm equation
Site index is total height at 30 years plantation age
Add 5 years to d.b.h. age to obtain plantation age (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2096	1.0027	-0.0671	1.2282	0.0335	0.99	1.50	1.1
SI	0.9618	0.9587	-0.0690	-0.7625	0.1719	0.99	1.49	1.2

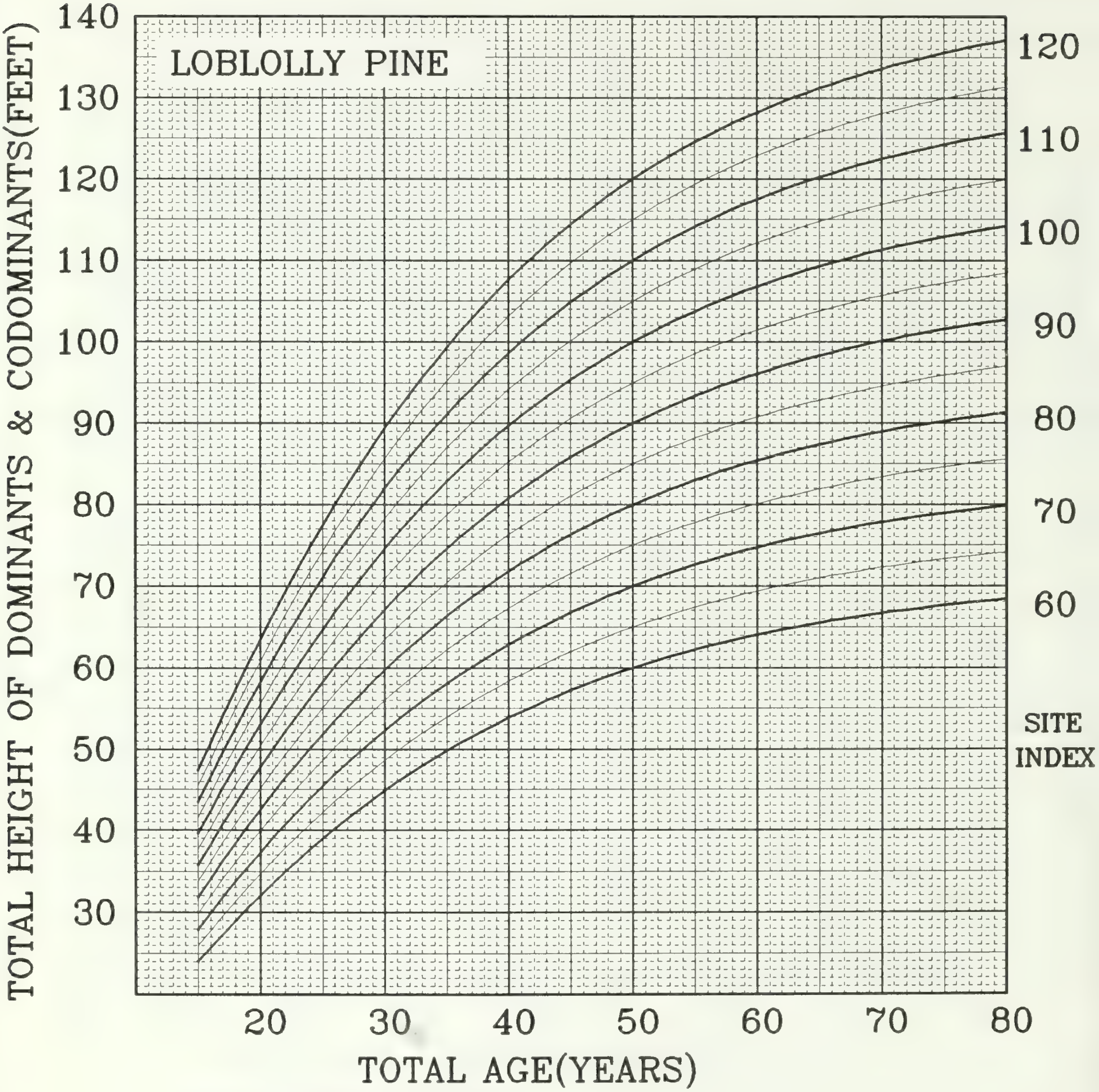

Figure 109.—Loblolly pine (USDA 1929)
Southern States
146 plots, number of dominants not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	76+
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1727	1.0042	-0.0439	1.3558	0.0240	0.99	0.50	1.7
SI	0.8765	0.9902	-0.0447	-1.2443	0.0502	0.99	0.60	2.1

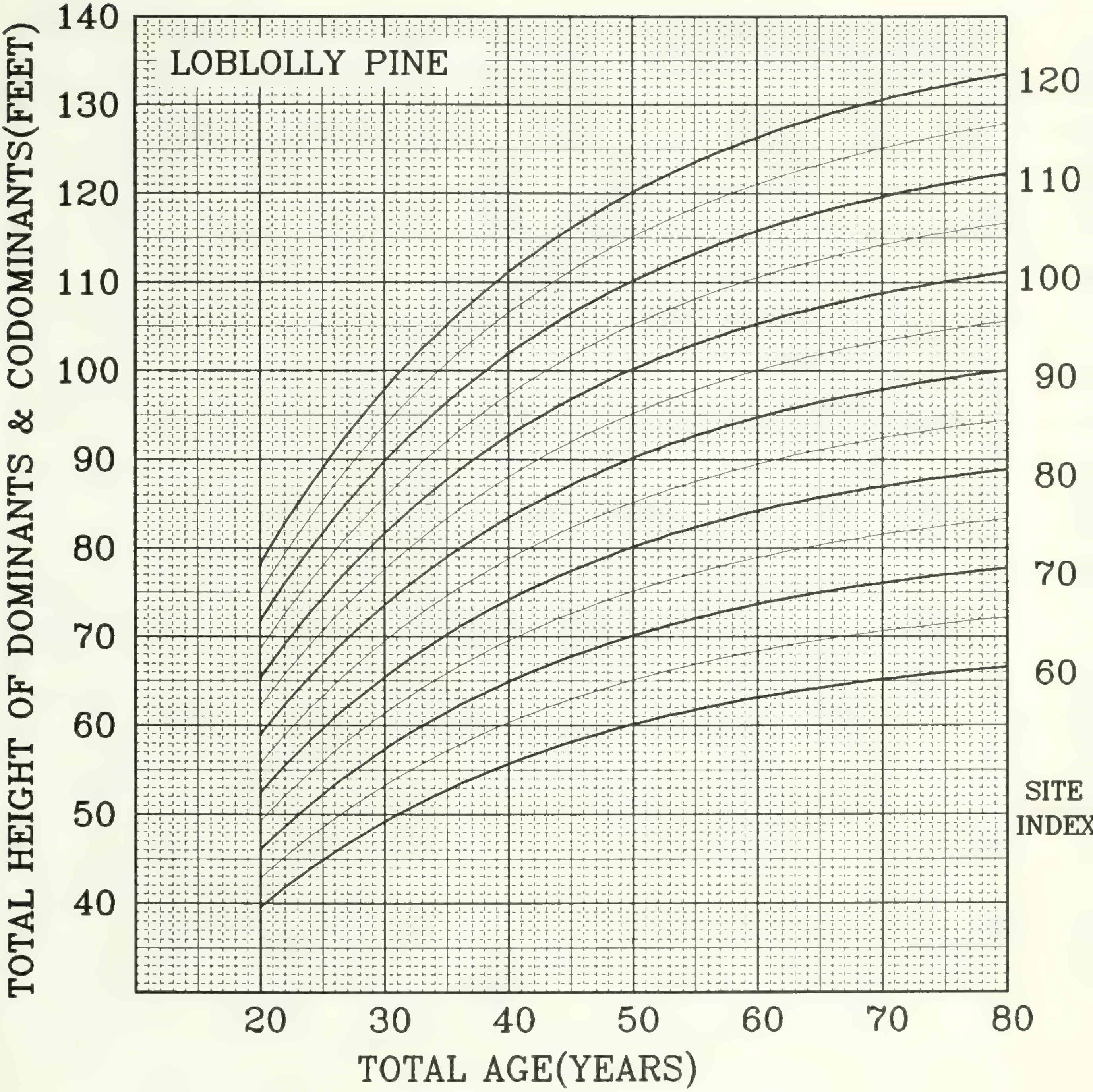

Figure 110.—Loblolly pine (Schumacher and Coile 1960, Coile and Schumacher 1964)

Coastal Plain from Chesapeake Bay, Maryland to Mobile Bay, Alabama
420 plots having 8 dominant and codominant trees on each plot
Total height and total age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	76+
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1421	1.0042	-0.0374	0.7632	0.0358	0.99	0.73	2.2
SI	0.8485	1.0038	-0.0389	-1.0031	-0.0145	0.99	0.82	3.0

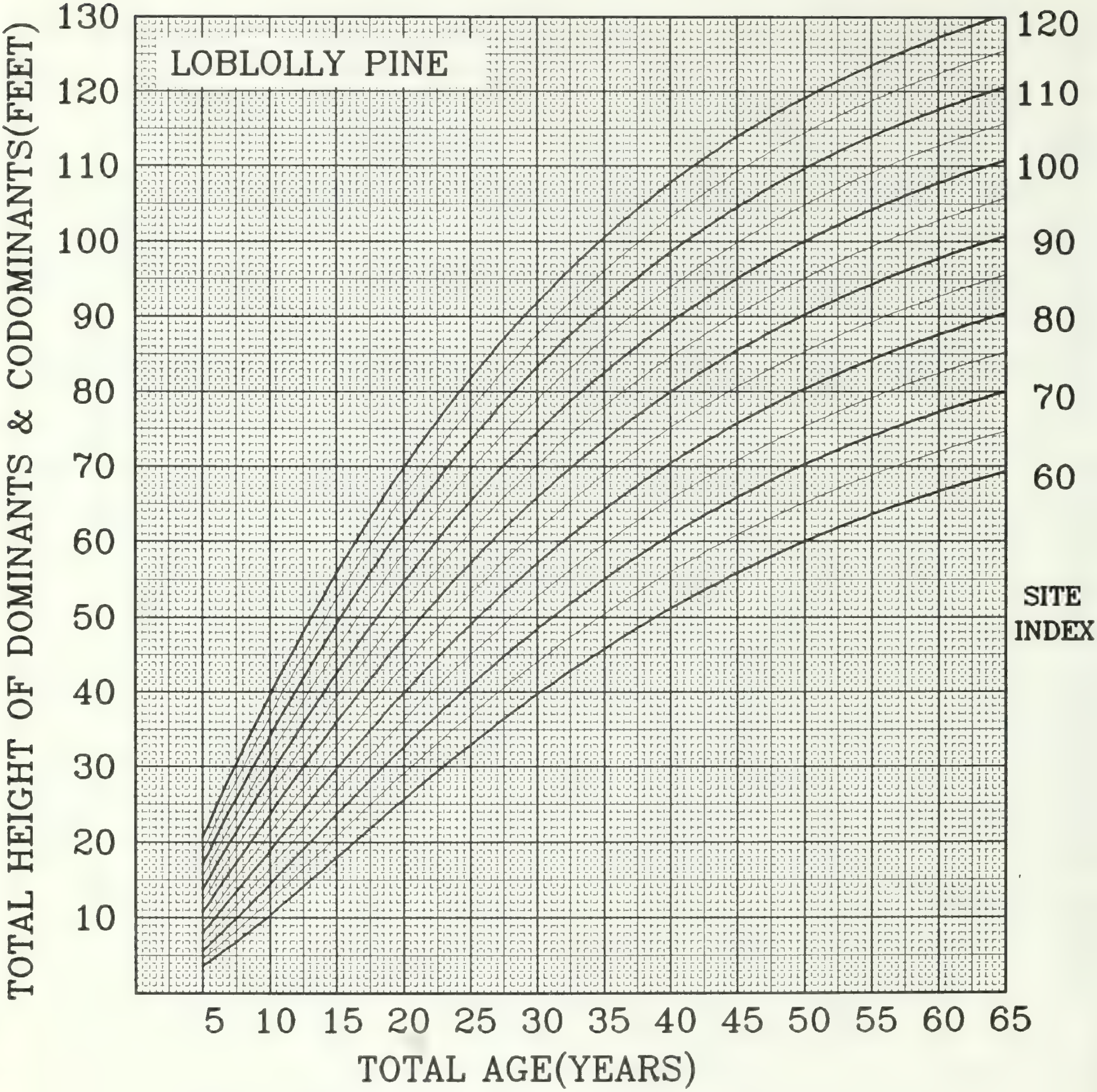

Figure 111.—Loblolly pine (Trousdell, Beck, and Lloyd 1974)
Coastal Plain of Virginia, North Carolina, and South Carolina
22 plots having 2 dominant and codominant trees on each plot
Stem analysis, polymorphic, nonlinear regression
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	76+
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	3.0849	0.8076	-0.0341	26.2342	-0.6702	0.99	1.45	5.2
SI	0.5694	1.0415	-0.0204	-1.4874	-0.1242	0.98	2.70	6.5

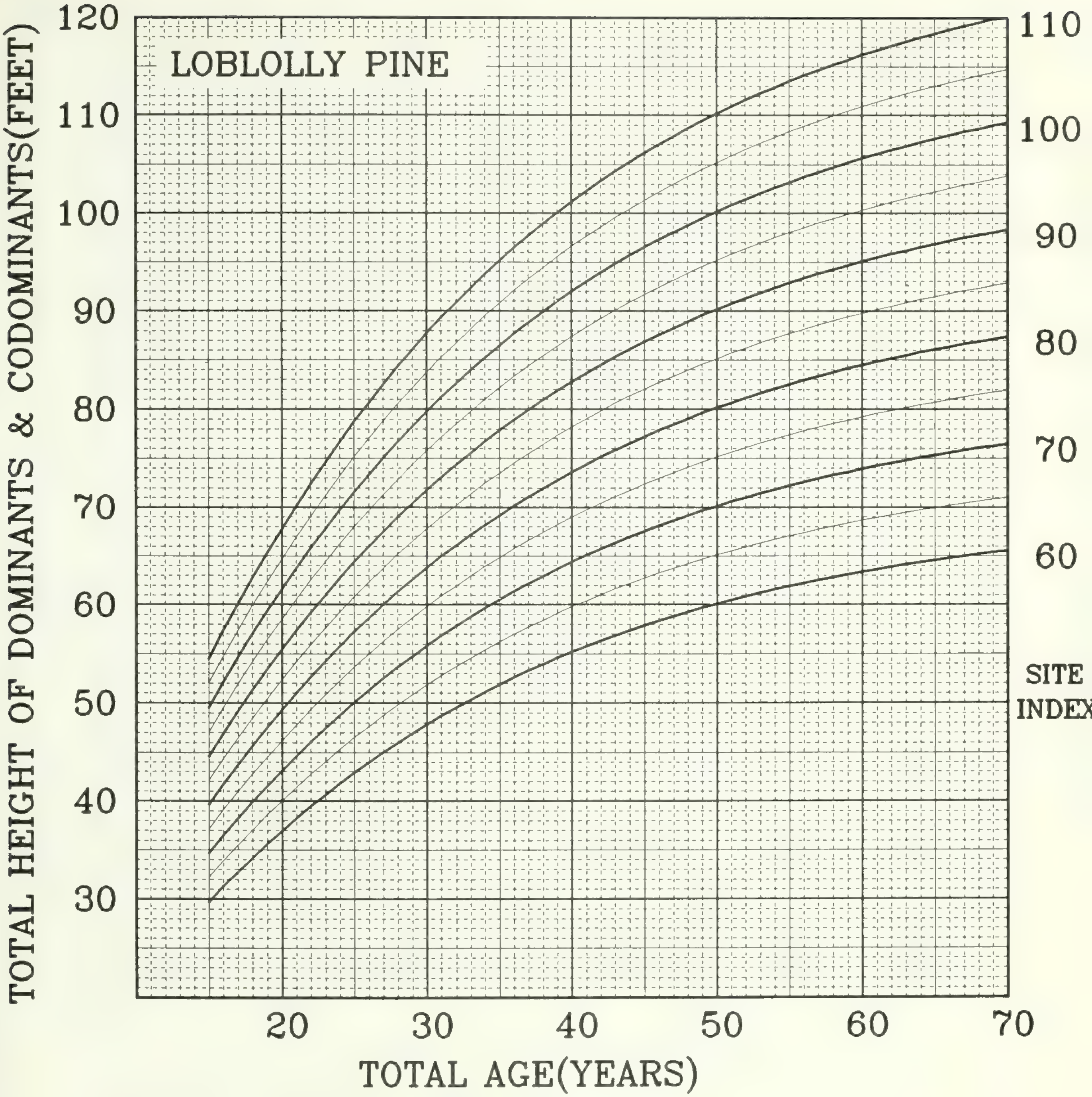

Figure 112.—Loblolly pine (Zahner 1962)

North Louisiana and southern Arkansas

211 plots on poorly aerated soils, number of dominant and codominant trees not given, additional site index curves given for loess soils and well-aerated soils

Total height and total age, anamorphic, age coefficient from soil-site regression

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	60-75	76+
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1643	0.9999	-0.0413	1.1057	-0.0002	0.99	1.12	3.5
SI	0.7973	1.0165	-0.0408	-1.6634	-0.0974	0.99	1.22	4.6

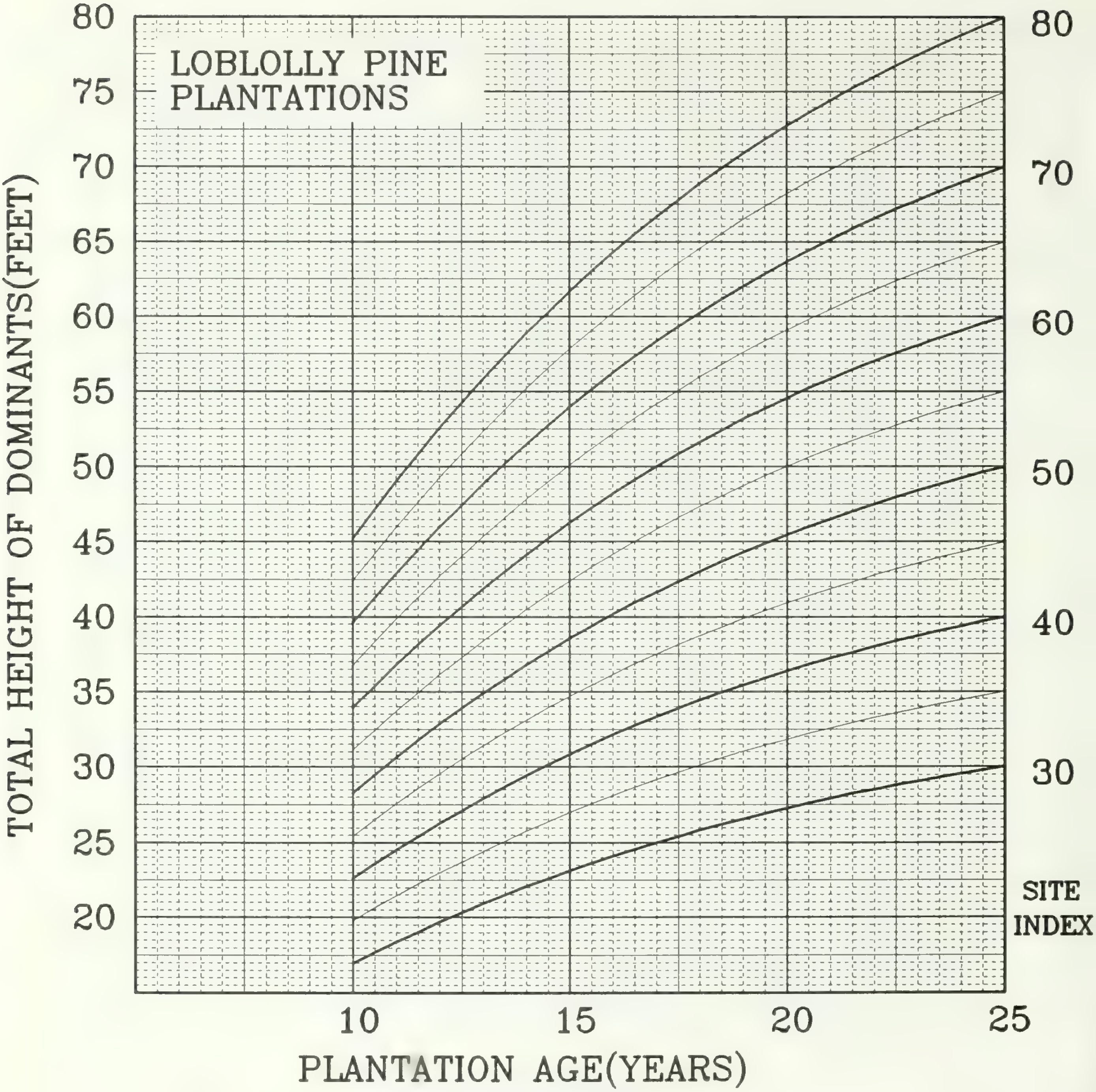

Figure 113.—Loblolly pine plantations (Shipman 1960)
South Carolina Piedmont
220 plantations, number of dominant trees not given
Total height and plantation age, anamorphic, logarithm equation
Site index is total height at 25 years plantation age
Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1579	1.0000	-0.0930	1.4274	0.0001	0.99	0.15	0.3
SI	0.9150	0.9936	-0.1123	-1.5988	0.0347	0.99	0.74	2.2

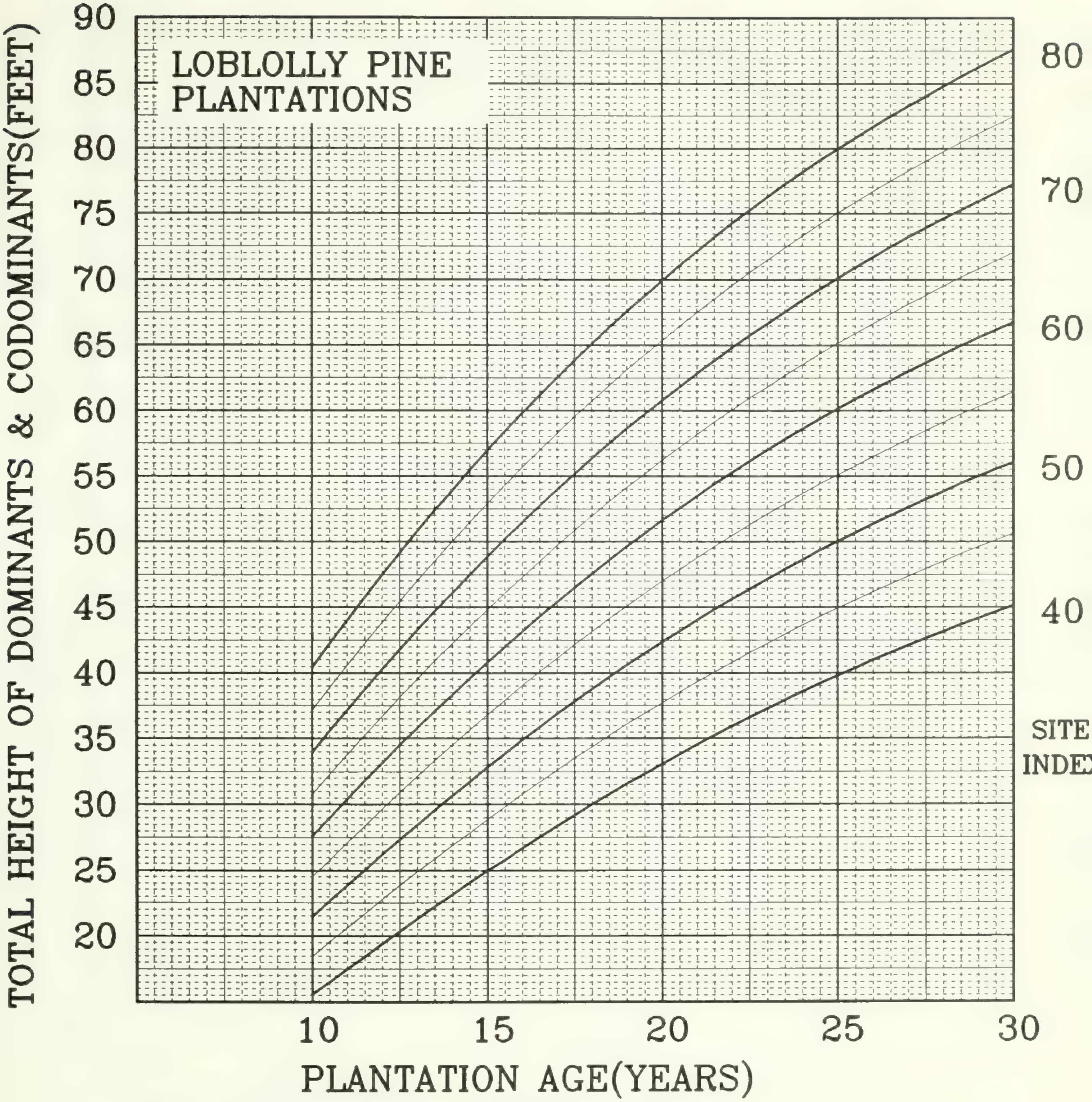

Figure 114.—Loblolly pine plantations (Clutter and Lenhart 1968)

Georgia Piedmont

141 dominant and codominant trees, number of plots not given

Stem analysis, polymorphic, nonlinear regression

Site index is total height at 25 years plantation age

Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.9579	0.8274	-0.0581	9.3221	-0.4616	0.99	0.37	1.3
SI	0.1483	1.2560	-0.0155	-2.5747	-0.2990	0.99	0.66	2.6

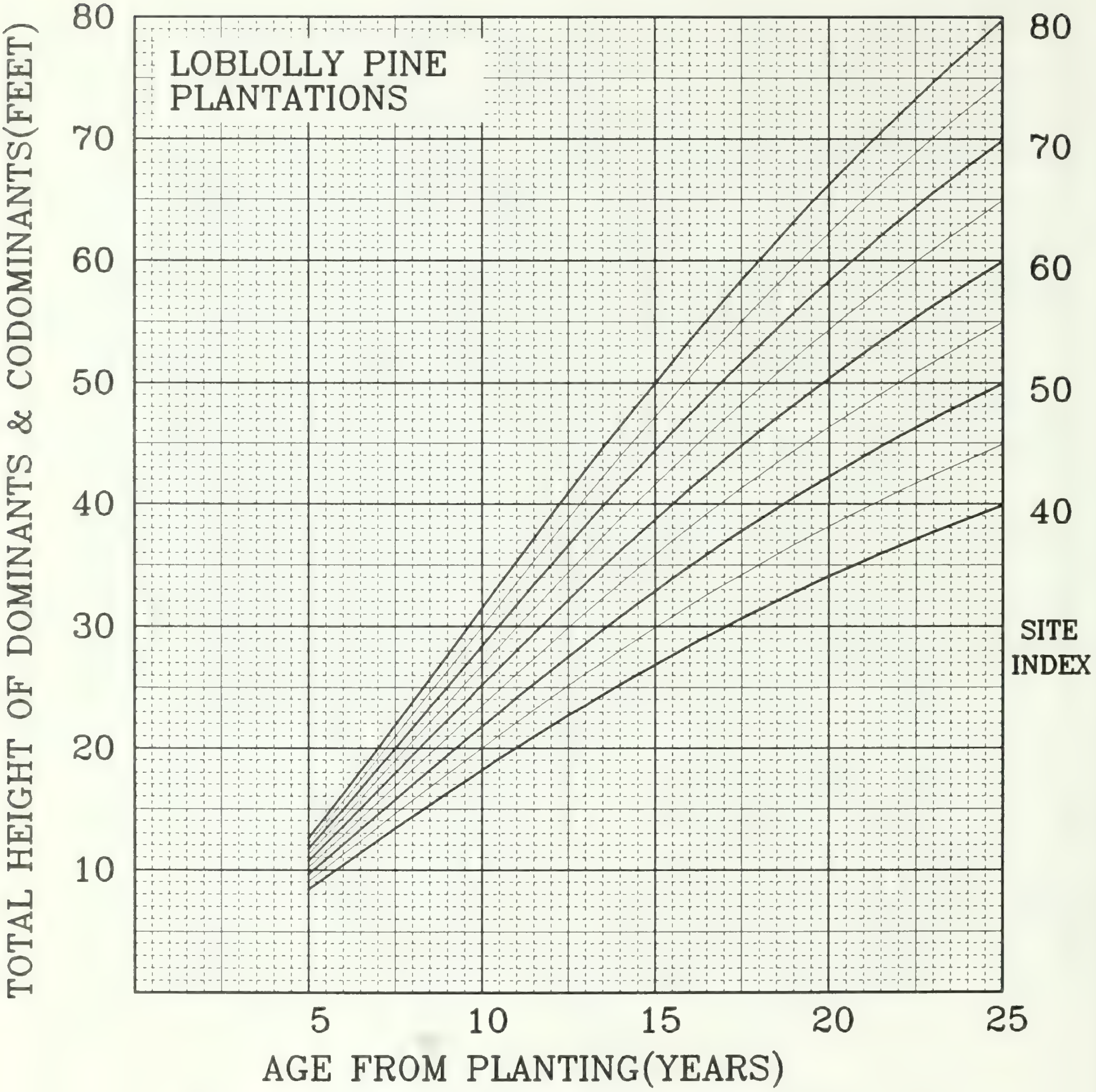

Figure 115.—Loblolly pine plantations--Piedmont (Amateis and Burkhart 1985)
Piedmont throughout most of natural range
68 plots, cutover and site prepared land, 1 dominant and 1 codominant tree on each plot
Stem analysis, differential equation, polymorphic
Site index is total height at 25 years since planting
Convert d.b.h. age to age since planting by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0060	1.1098	-0.0535	0.5548	0.2433	0.99	0.01	0.4
SI	0.8459	1.0028	-0.1241	-1.4067	0.2398	0.99	0.01	3.4

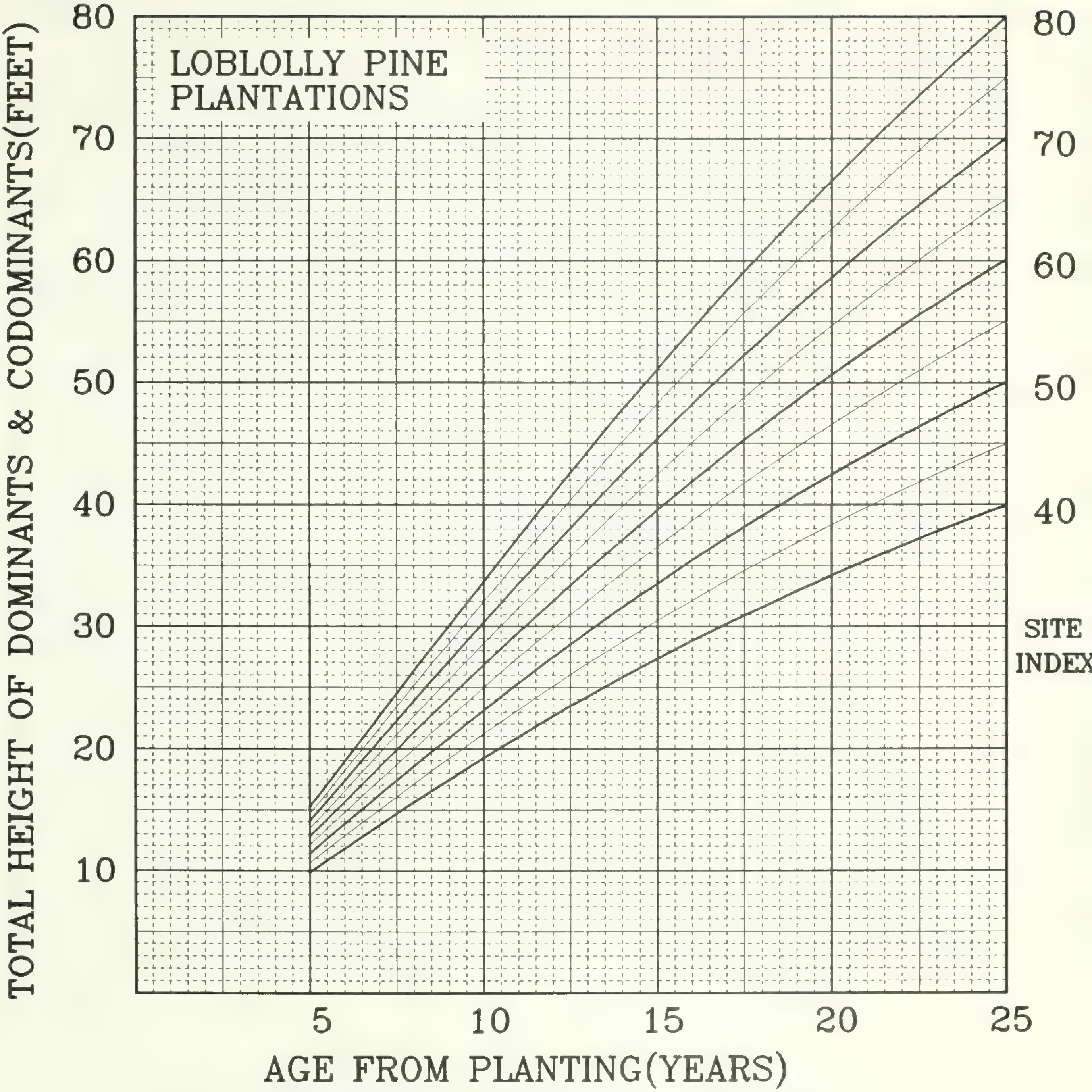

Figure 116.—Loblolly pine plantations--Coastal Plain (Amateis and Burkhart 1985)
Coastal Plain throughout most of natural range
105 plots, cutover and site prepared land, 1 dominant and 1 codominant tree on each plot
Stem analysis, differential equation, polymorphic
Site index is total height at 25 years since planting
Convert d.b.h. age to age since planting by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	3	2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0107	1.1384	-0.0393	0.4584	0.2413	0.96	0.78	0.5
SI	0.9172	0.9646	-0.0982	-1.0330	0.2288	0.99	1.96	3.5

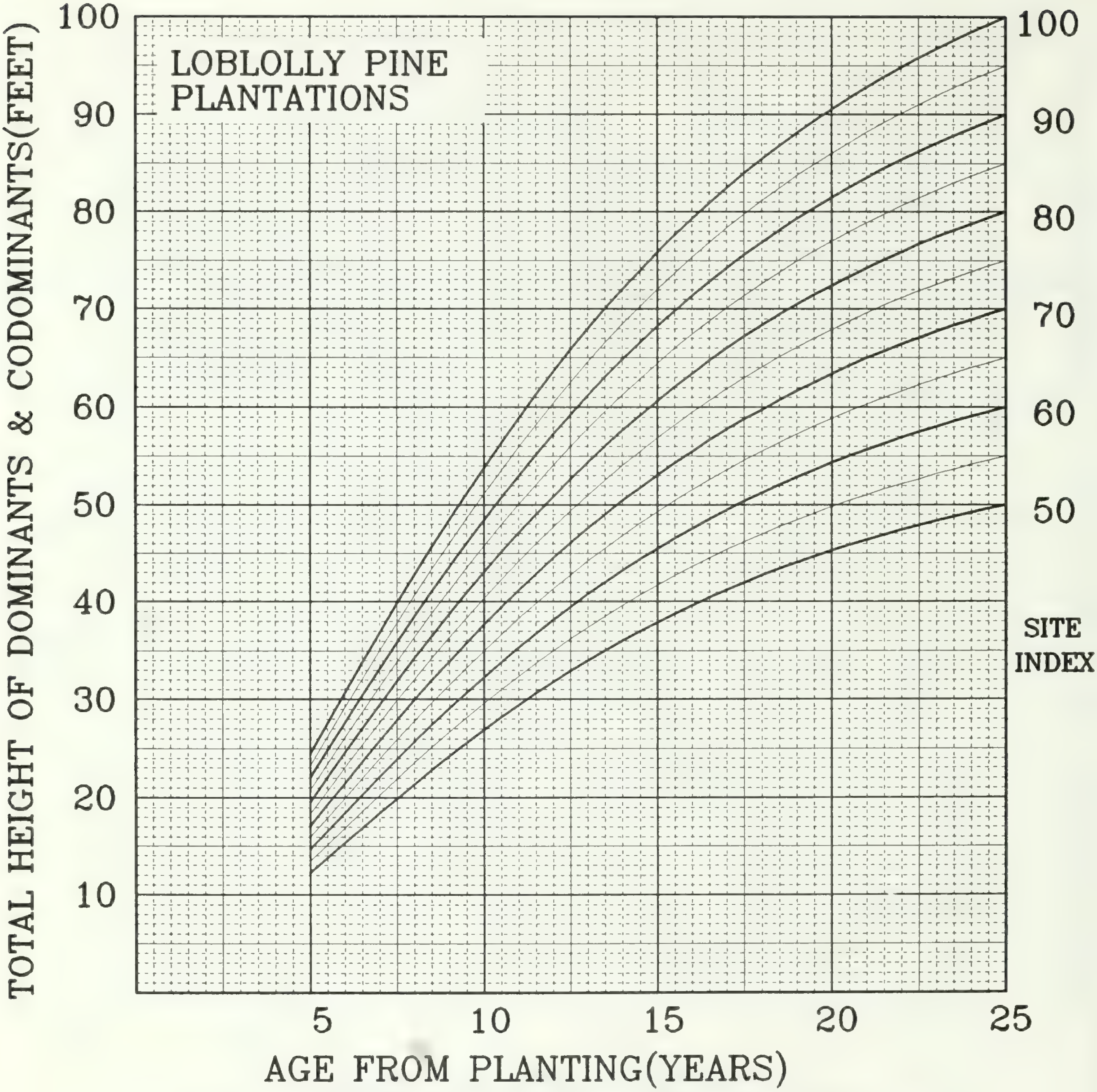

Figure 117.—Loblolly pine plantations--well drained (Pienaar and Shiver 1980)

Coastal plains of North and South Carolina—all except very poorly drained soils

154 plots, site prepared lands, 2 dominant and codominant trees on each plot

Stem analysis, nonlinear regression, anamorphic

Site index is total height at 25 years since planting

Convert d.b.h. age to age since planting by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1519	1.0000	-0.1003	1.6640	0.0001	0.99	0.08	0.01
SI	0.8680	1.0000	-0.1003	-1.6650	-0.00004	0.99	0.10	0.02

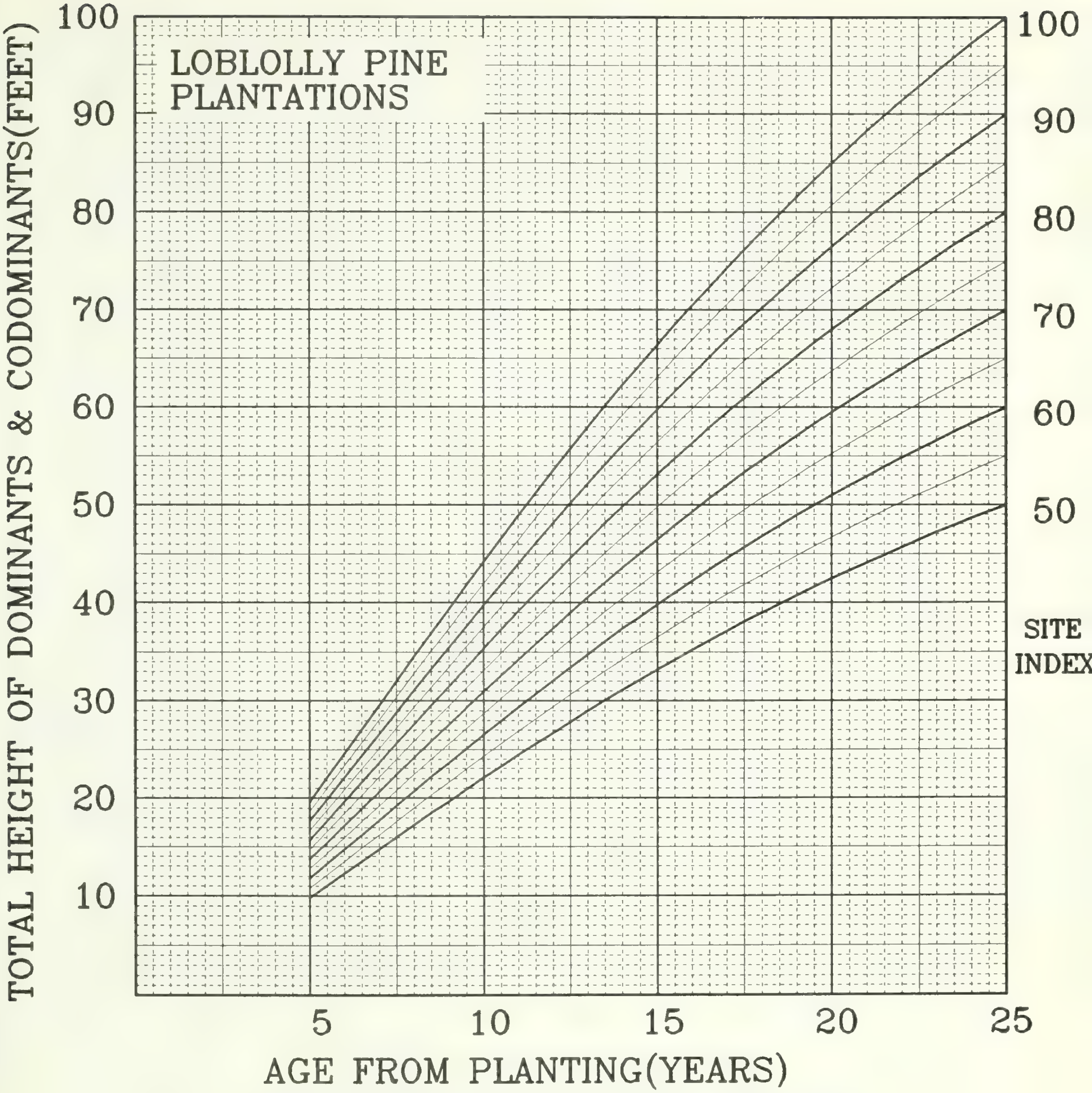

Figure 118.—Loblolly pine plantations--poorly drained (Pienaar and Shiver 1980)

Coastal Plains of North and South Carolina—very poorly drained soils in pocosins

25 plots, site prepared lands, 2 dominant and codominant trees on each plot

Stem analysis, nonlinear regression, anamorphic

Site index is total height at 25 years since planting

Convert d.b.h. age to age since planting by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5177	1.0000	-0.0551	1.4360	-0.0001	0.99	0.08	0.01
SI	0.6596	0.9998	-0.0551	-1.4347	0.0002	0.99	0.11	0.02

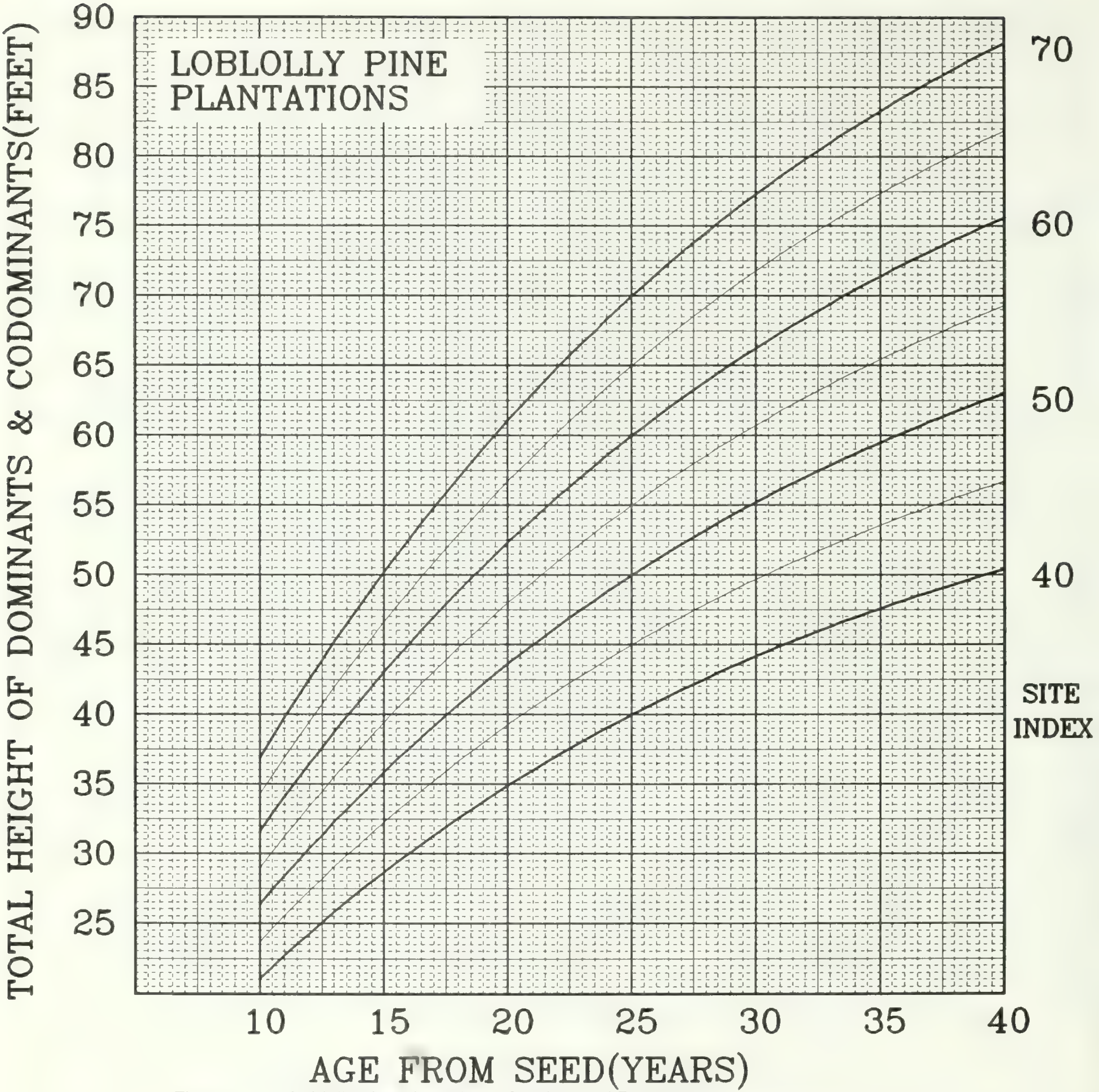

Figure 119.—Loblolly pine plantations (Smalley and Bower 1971)

Central Tennessee, Northern Alabama, and Northwest Georgia
270 plantations, number of dominant and codominant trees not given
Total height and age from seed, anamorphic, logarithm equation
Site index is total height at 25 years age from seed
Convert d.b.h. age to age from seed by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.5861	0.9999	-0.0390	0.9753	-0.0017	0.99	0.28	0.7
SI	0.5990	1.0131	-0.0394	-1.0892	-0.0272	0.99	0.32	1.1

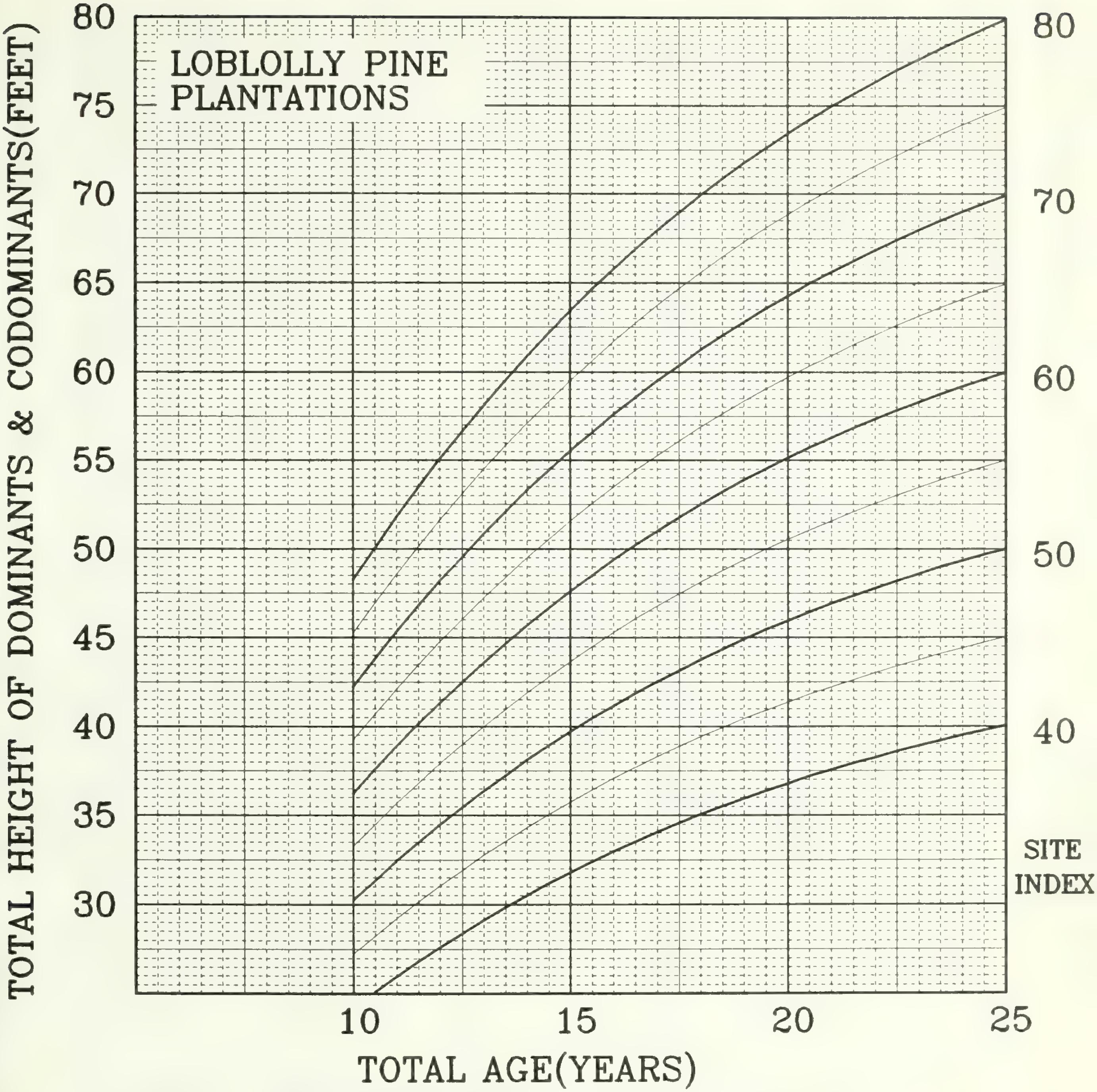

Figure 120.—Loblolly pine plantations (Lenhart 1971)

Interior West Gulf Coastal Plain of Texas, Louisiana, and Arkansas
699 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, logarithm equation
Site index is total height at 25 years total age
Convert d.b.h. age to total age by adding years according to
site index (BH = 0.0):

SI:	<50	>50
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1547	0.9973	-0.0915	1.2294	0.0029	0.96	0.59	0.8
SI	0.8550	1.0066	-0.0931	-1.3579	-0.0163	0.97	0.65	1.2

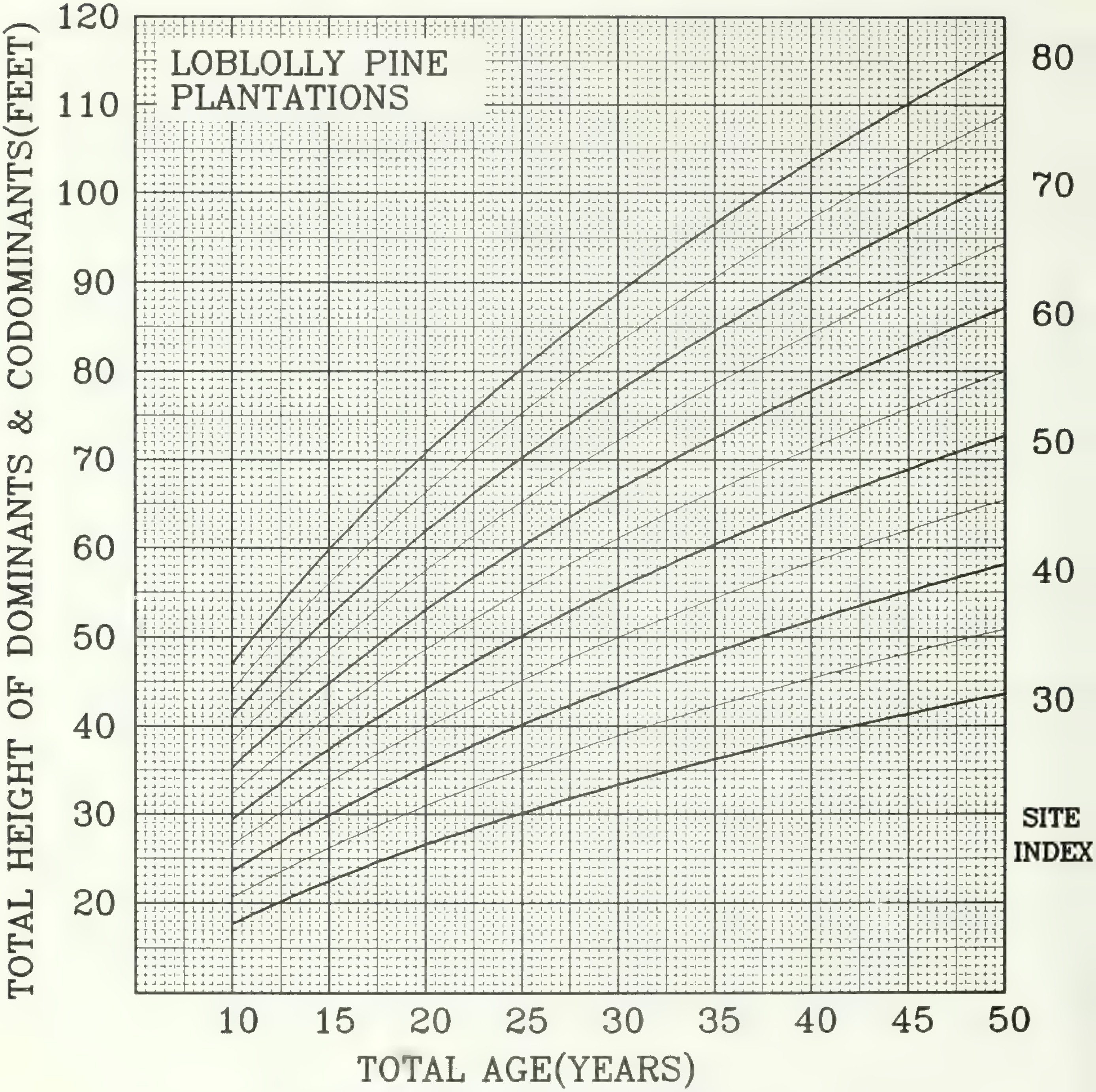

Figure 121.—Loblolly pine plantations (Popham *et al.* 1979)

Lower West Gulf Coastal Plain of eastern Texas, Louisiana, Arkansas, and Alabama

293 permanent growth plots on cutover sites, number of dominant and codominant trees not given

Remeasurements of total height and total age, anamorphic, regression equations

Site index is total height at 25 years total age

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<50	>50
Years:	4	3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.7644	0.9991	-0.0090	0.6293	0.0003	0.99	1.20	4.9
SI	0.2937	1.0738	-0.0112	-0.9033	-0.0801	0.99	1.42	6.9

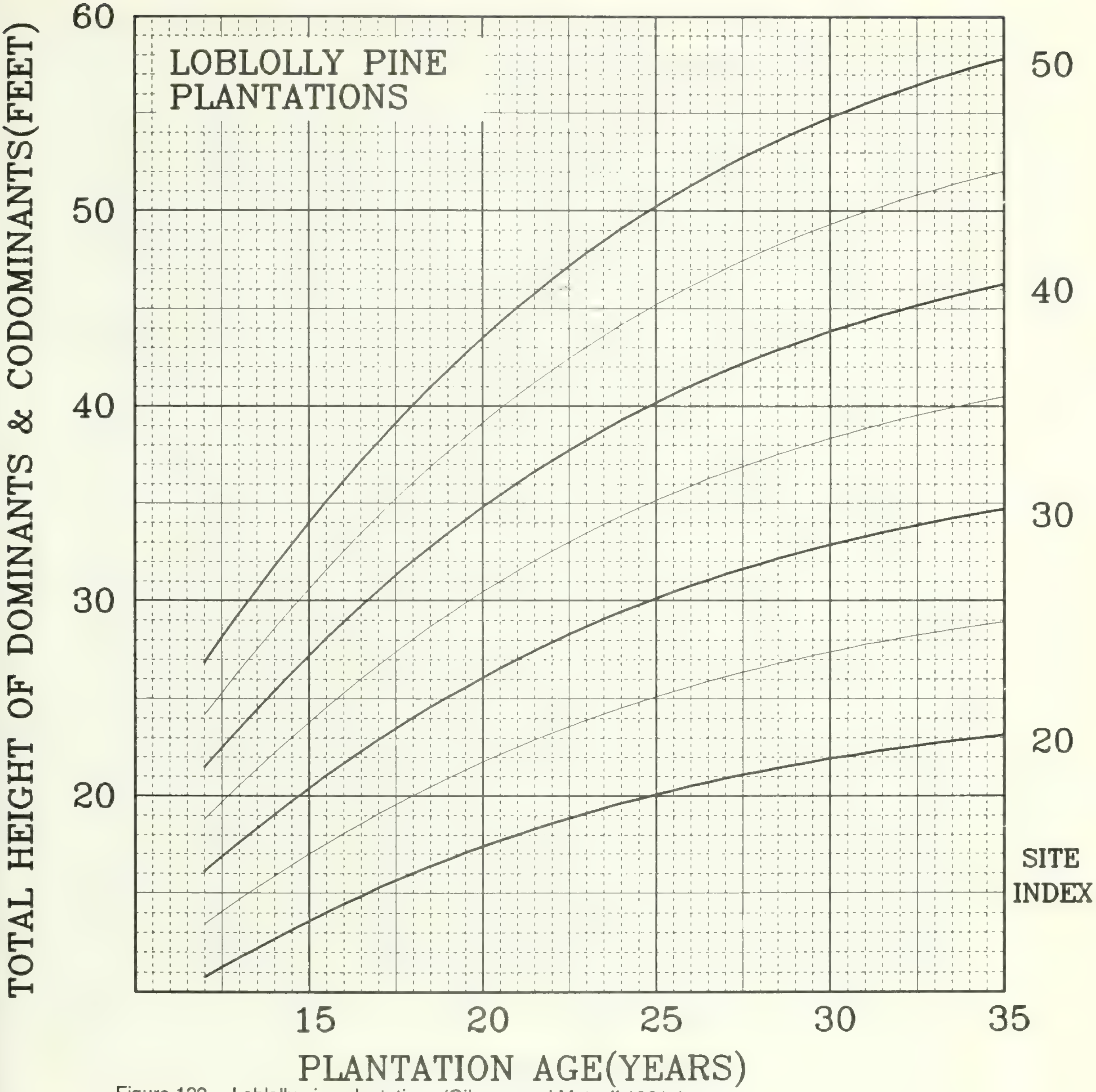

Figure 122.—Loblolly pine plantations (Gilmore and Metcalf 1961a)
Southern Illinois
53 plantations, number of dominant trees not given
Total height and plantation age, anamorphic, logarithm equation
Site index is total height at 25 years plantation age
Convert d.b.h. age to plantation age by adding years according to site index (BH = 0.0):
SI: <35 >35
Years: 4 3

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2697	1.0002	-0.0885	2.0238	0.0006	0.99	0.73	2.3
SI	0.7050	1.0303	-0.0860	-2.7362	-0.1026	0.99	1.17	3.8

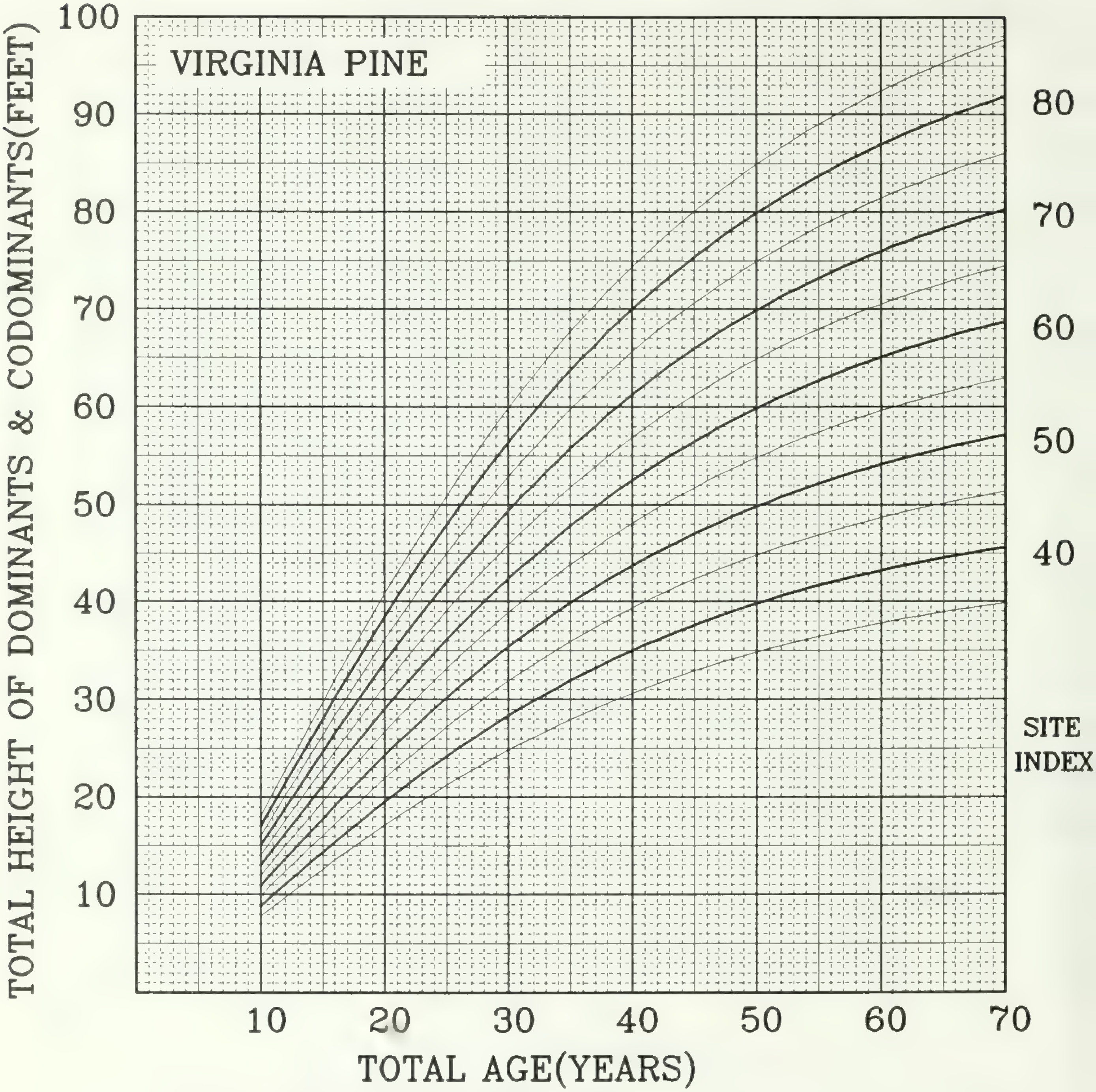

Figure 123.—Virginia pine (Slocum and Miller 1953)
Piedmont of Durham County, North Carolina
116 plots, number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<45	45-75	>75
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.2096	1.0140	-0.0380	1.3247	0.0374	0.99	0.87	3.7
SI	0.9100	0.9645	-0.0396	-1.0279	0.1133	0.99	1.10	5.6

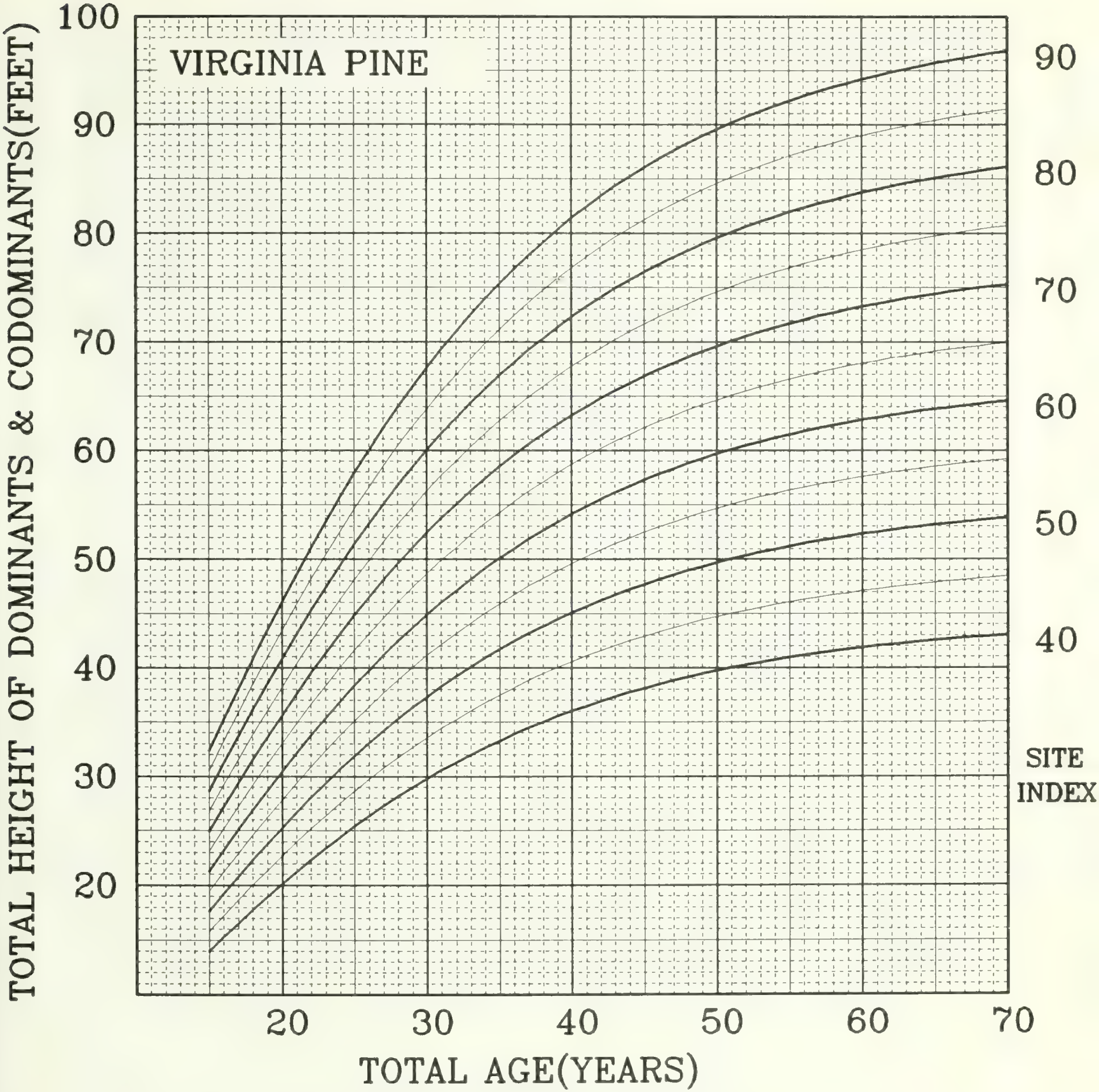

Figure 124.—Virginia pine (Chaiken and Nelson 1959; Nelson, Clutter, and Chaiken 1961)

Piedmont of Maryland, Virginia, and the Carolinas

166 plots, number of dominant and codominant trees not given

Total height and total age, anamorphic, logarithm equation not given

Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<45	45-75	>75
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.1204	0.9984	-0.0597	2.4448	-0.0284	0.99	0.92	4.6
SI	0.8421	1.0090	-0.0490	-2.1682	-0.0762	0.99	0.99	4.3

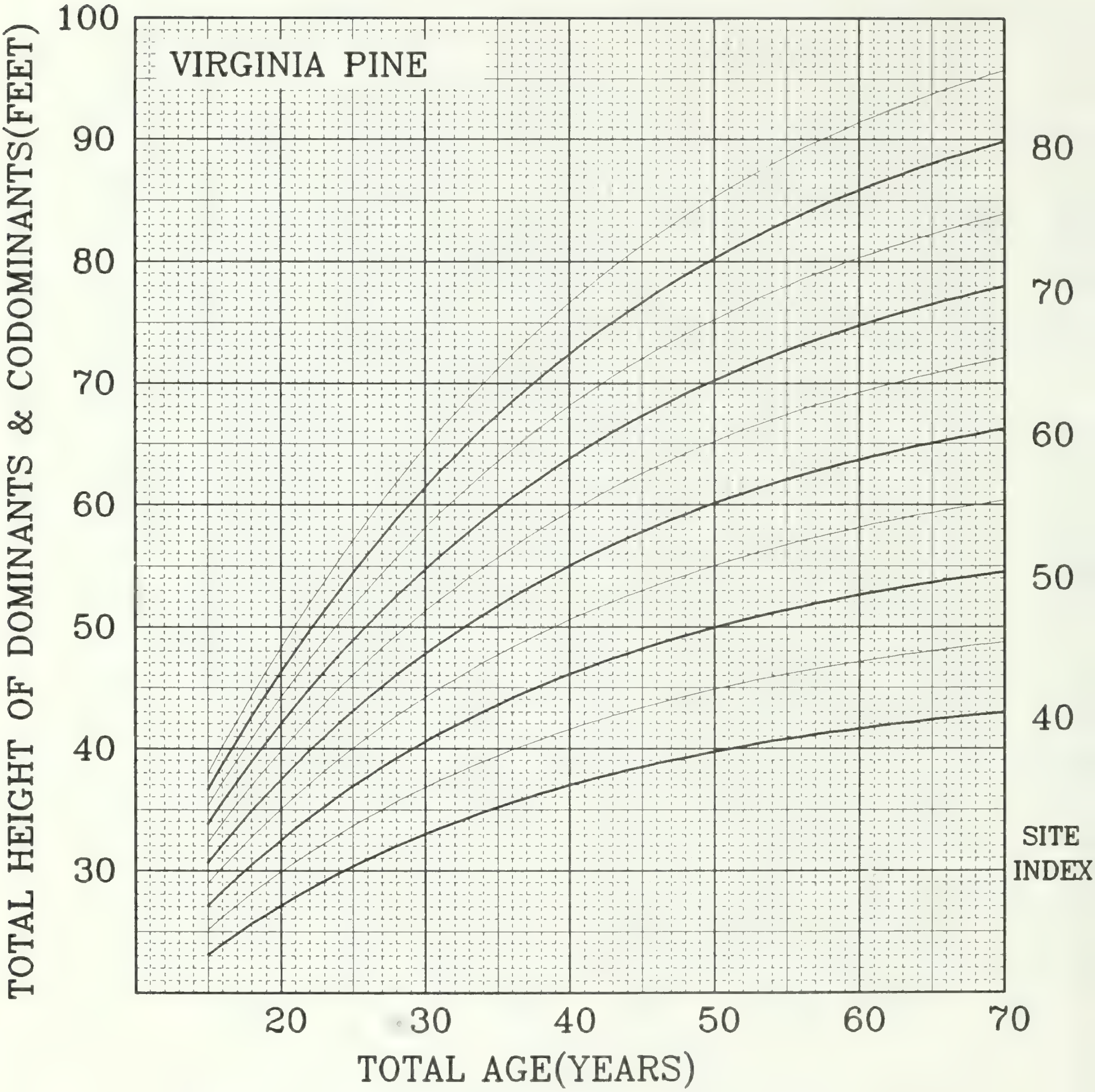

Figure 125.—Virginia pine (Kulow, Sowers, and Heesch 1966)
West Virginia, Maryland, and Pennsylvania
922 dominant and codominant trees, number of plots not given
Total height and total age, anamorphic, logarithm equation
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	<45	45-75	>75
Years:	6	5	4

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	0.7716	1.1087	-0.0348	0.1099	0.5274	0.99	0.88	3.1
SI	1.0955	0.9455	-0.0527	-0.3886	0.3628	0.99	1.25	4.3

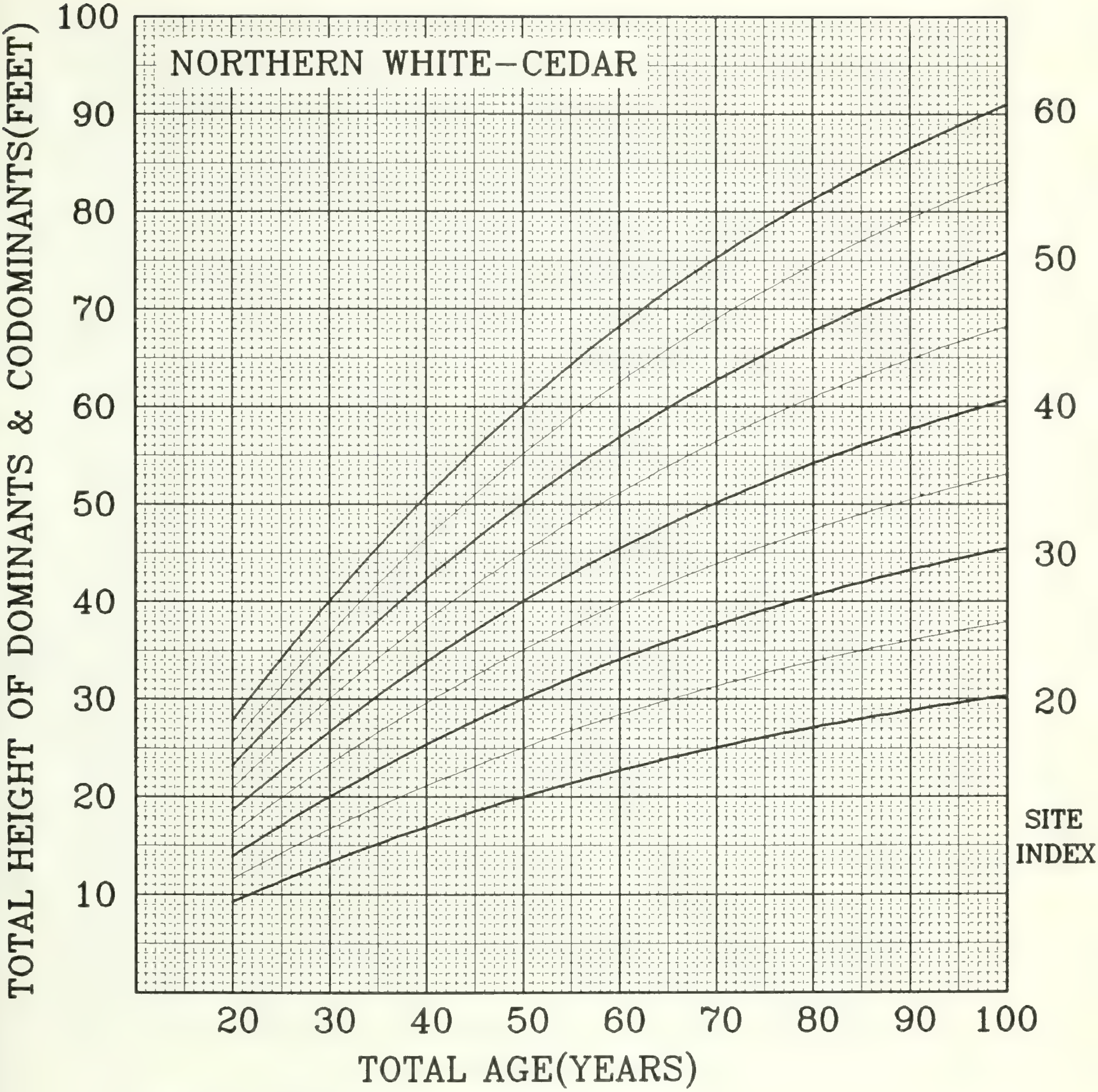

Figure 126.—Northern white-cedar (Gevorkiantz 1957e)
Lake States
Number of plots and number of dominant and codominant trees not given
Total height and total age, anamorphic, equation not given
Convert d.b.h. age to total age by adding years according to site index (BH = 0.0):

SI:	20	30	40	50	60
Years:	20	15	15	10	10

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.9730	1.0000	-0.0154	1.0895	0.0000	0.99	0.66	1.7
SI	0.5068	1.0000	-0.0154	-1.0895	0.0000	0.99	0.66	1.7

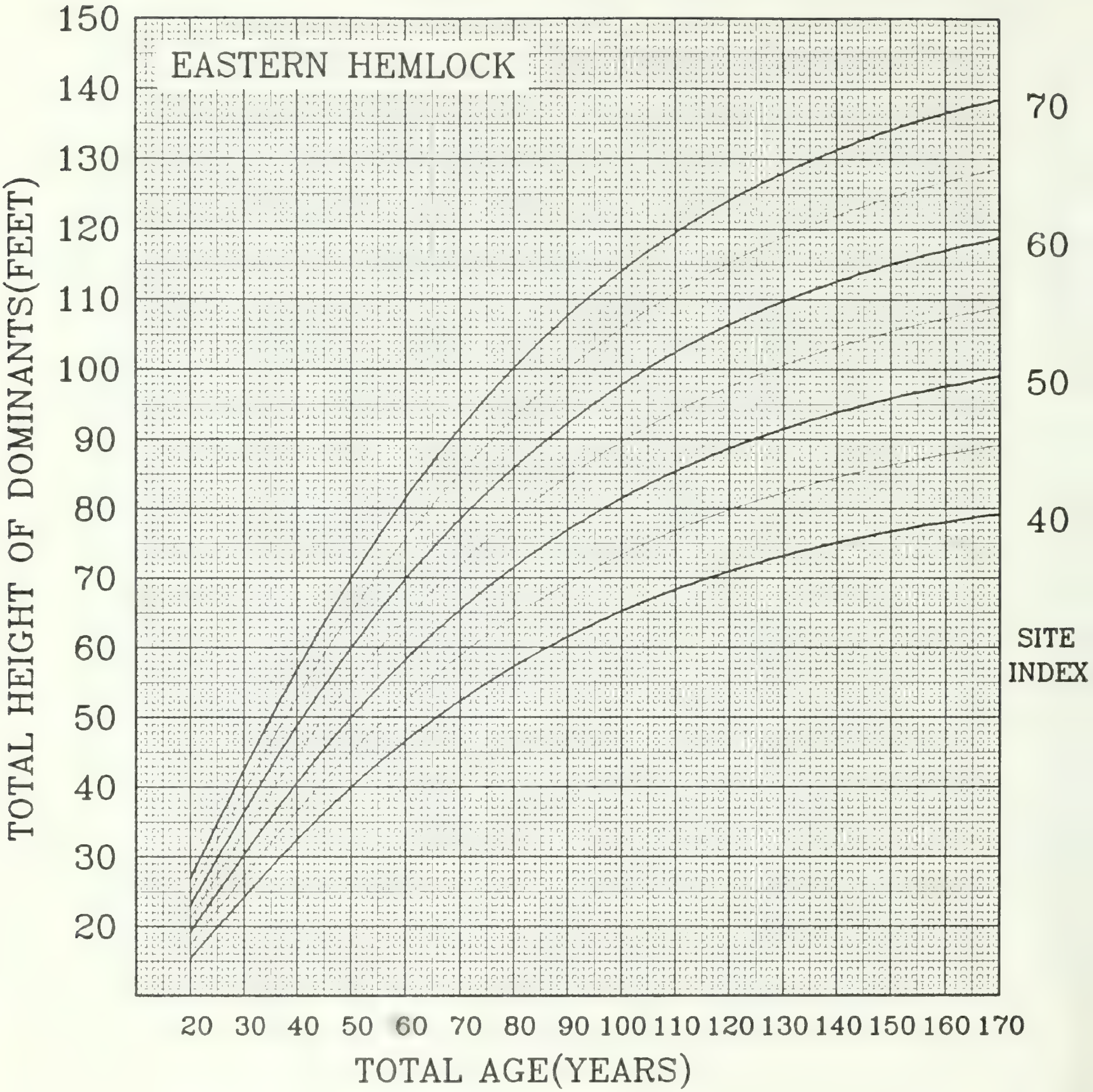

Figure 127.—Eastern hemlock (Frothingham 1915a)

Based on average of "maximum" height growth curves from stands in New York, Michigan, and Southern Appalachian Mountains

Number of plots and number of dominant trees not given

Total height and age, anamorphic, equation not given

Add 6 years to d.b.h. age to obtain total age. Vigorous uninjured free-growing dominants in even aged stands are particularly important for estimating site index of hemlock (BH = 0.0)

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	2.1493	0.9979	-0.0175	1.4086	-0.0008	0.99	0.50	1.6
SI	0.2172	1.1309	-0.0105	-1.9120	-0.1327	0.99	1.20	3.4

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Carmean, Willard H.; Hahn, Jerold T.; Jacobs, Rodney D.
1989. Site index curves for forest species in the eastern United States. Gen. Tech. Rep. NC-128. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 142 p.

Site index curves are given for forest tree species found in the eastern United States. A total of 127 site curves are presented including formulations for computing both total height and site index.

KEY WORDS: Site quality estimation, formulations for height growth and site index.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL
FOREST
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United States Department of Agriculture

Forest
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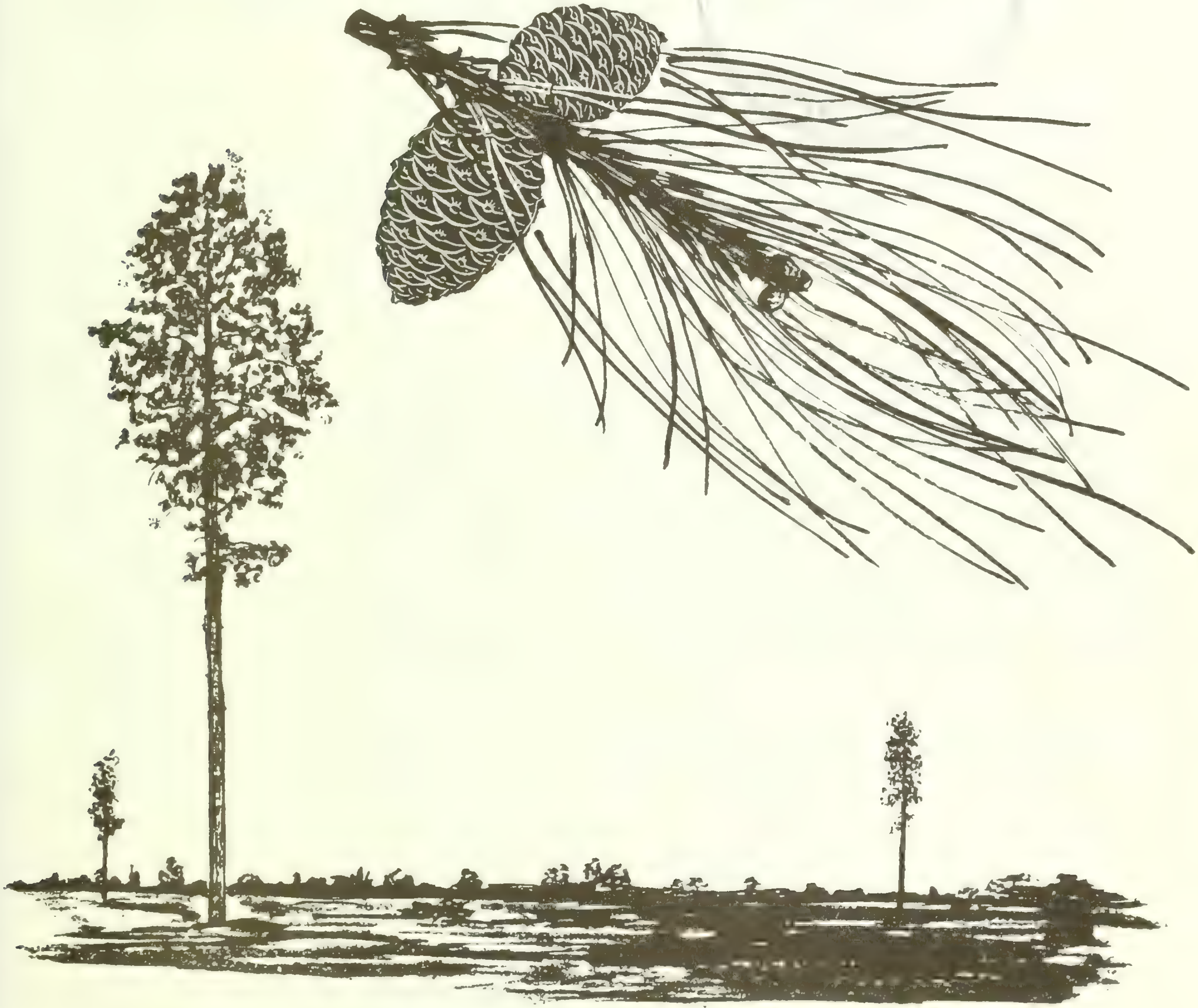
North Central
Forest Experiment
Station

General Technical
Report **NC-129**

Fire Effects in Northeastern Forests: Red Pine

Cary Rouse



Preface

This is the fourth in a series of papers dealing with fire effects in northeastern forests. The 21-State region incorporates many diverse ecosystems--the northern hardwoods of New England, the boreal forests of Minnesota, the oak-hickory forests of Missouri, and fine hardwoods in the Central States. Although all forests have some aspects in common, each ecosystem responds somewhat differently to fire. Although we in the Northeast know less about our fire ecology than people in other regions know about theirs, a small body of information is scattered throughout the literature. The purpose of this series is to gather this information in one place and make it readily available to managers. Each paper in the series summarizes the literature, and readers can obtain detailed information on specific topics from the accompanying references. Other papers available in the series include: aspen, oak, and jack pine.

Acknowledgment

I would like to thank Fred McCauley for his excellent cover design.

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"... almost every forest climax of North America displays a fire subclimax ..." (19).

Fire is Important

Fire has played a major role in the forest ecosystems of North America. The place of fire in red pine (*Pinus resinosa*) regeneration has long been a subject for speculation and experimentation. Although researchers have recognized fire as important (39), much of the literature lacks the prefire vegetation, weather, and fire behavior documentation necessary to predict fire effects. Without such information, comparisons among and predictions of effects from fires become questionable at best. This report summarizes existing information about the effects of fire on the red pine forest type in eastern North America and suggests silvicultural uses of prescribed fire in red pine.

HISTORY

Fire Cycles and Strategies

In several studies in the North Central States and adjacent Canadian Provinces (14, 21, 34), researchers used historical records and/or dendrochronological data to determine fire frequency. They found that before European settlement, fires occurred at intervals ranging from 14 years (14) to 50 years (41). Heinselman (21) reported that frequent severe fires usually discourage red pine establishment and encourage jack pine. Because open-grown red pine does not normally bear cones until it is about 20 to 25 years old (17), at least one fire-free period of that duration is necessary to produce seeds for regeneration. On the other hand, jack pine can bear cones when 3 to 5 years old (13); although more typically jack pine produces them between 10 and 15 years of age. When heat opens these serotinous cones, seeds can be regularly distributed by frequent forest fires.

Mutch (29) hypothesized that plant communities in repeatedly burned areas evolve to become more flammable to maintain themselves. Fire-adapted plants have evolved three main responses to fire:

1. Mature stands die after fire. These species often produce dense, even-aged stands that promote severe fires. When a fire occurs, it may regenerate the stand. Jack pine is an example of such a species (32).
2. Stands resprout after fire. The ability of the plant to sprout after fire is a primary characteristic of these species. They can be perpetuated after a fire of almost any severity. Aspen is an example of a species with this response to fire.

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3. Mature stands generally live after fire. These species have characteristics (e.g., insulating bark) that help them survive a fire. Red pine is an example.

Red Pine Response

Generally, red pine has developed thicker bark and grows taller than its associates such as white pine and spruce (17, 20). In addition, red pine seeds germinate best in close, if not direct, contact with mineral soil (2). Given such characteristics, it is likely that fire enhances the natural regeneration of red pine.

Before the Europeans arrived, fires probably burned until they met an obstacle (such as a river, lake, or change in cover type) or until weather conditions changed and made fuels less flammable. After settlement and logging, much more intense fires burned through logging slash, destroying the humus layer and leaving only mineral soil (5). Some fires were so destructive that sites originally occupied by red pine reverted to jack pine (16). Similarly, some sites previously occupied by white pine sometimes reverted to red pine (20).

FIRE EFFECTS

Factors

Several factors determine if fire injures or kills a tree. In red pine they include lethal temperature, season, bark characteristics, size and vigor of tree, and specific fire characteristics.

Lethal Temperature

Fire can injure or kill any living tissue, including the cambium and needles of a red pine tree. Researchers have shown that when living tissue reaches 147°F (64°C), it dies almost instantaneously (6). Although this temperature is a good general figure, the death of plant tissue is a function of both temperature **and** time.

Season

During the winter, most trees are generally less susceptible to injury because they are dormant (18). Dormant buds—the next year's growth—are well protected (42). In addition, because ambient air temperature is lower in the winter than at other times of the year, a more intense fire is necessary to raise a tree's internal temperature to the lethal point (6). In the natural range of red pine, snow usually negates the possibility of fires in the winter.

In spring, the litter layer is winter cured and dry; the duff fermentation and humus layers are moist. Wildfires spread quickly in red pine stands, yet they burn shallowly, causing little damage to the soil or roots. Vigorous re-sprouting normally follows these spring fires.

During the summer, the moisture content of herbaceous fuels is high, making wildfire occurrence unlikely. Soil moisture is normally high then as well. However, during periods of extended drying, the moisture content of the duff and humus layers decreases, and herbaceous fuels that are normally green become cured. Fires occurring during these periods burn deeply, cause severe root damage, and greatly reduce sprouting of shrubs and hardwoods.[1] Because brush is the worst enemy of red pine reproduction, fires that reduce understory "... can be of benefit to red pine" (16).

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[1] *Personal communication from John W. Benzie, Project Leader, Forestry Sciences Laboratory, Grand Rapids, MN; June 10, 1987.*

Fall burns can be similar to both spring and summer burns. If there is adequate soil moisture, only surface fuels (newly fallen leaves and cured herbaceous material) are consumed. Root damage can be even less severe than during spring burns because the litter layer has often not been completely cured. If fall burns occur in conjunction with periods of extended drying, however, they can cause severe root damage.

Bark

Bark insulates and protects the tree's cambium. Although thermal conductivity of bark is an important factor in a tree's susceptibility to fire, bark thickness is equally important (and much easier to measure). Bark thickness in most species is related to age "... the older the tree, the thicker the bark, and consequently the more resistant the tree to fire" (6). Red pine is well known for its ability to produce thick bark and in old age is particularly resistant to fire (39).

Size and Vigor Play a Related Role

Until a red pine tree is 60 feet tall (roughly 50 years old), either the basal cambium or the crown can be killed. Once the tree reaches this height, however, the bark is thick enough to protect the cambium from all but the most extreme fires (39). Although tall trees are still susceptible to crown damage, they may survive even though 85 percent of their original crown was scorched (26, 40).

Large trees are able to survive intense fires more often than small trees (23, 37) because large trees have a larger area of cambium that can continue to function if a portion is killed. The potential longevity (100+ years) of red pine allows for the development of trees 2 or more feet in diameter (20).

Fire Characteristics

Fire characteristics differ among fires and even within a fire. Fire behavior depends upon several factors—most importantly, fuel characteristics and weather (13). Red pine stands contain flammable fuels in the form of deep, loose needle litter (39). The amount of litter produced is based on the site index and stand density. Red pine stands on better sites (S.I. 60+) produce more fine fuels than those on poorer sites, but production drops off and reaches an equilibrium soon after crown closure. Although litter is produced faster on better sites than on poorer ones, crown closure also occurs sooner on better sites, thus shortening the period when wildfires are likely to crown (7, 22). (Once the crowns close, lower branches die and a widening gap develops between the ground and the lower crown.)

Byram's (11) fire intensity model measures fire behavior in terms of heat released per unit time per unit length of fire line. Greater fire intensity means that more energy is directed at the tree, and the probability of injury increases. Fireline intensity is the product of energy contained in the fuel, fuel consumption, and rate of spread. The intensity of a flaming front can also be estimated from flame length. Methods (with or without instruments) to estimate both rate of spread and flame length in the field have been devised (4, 31, 35).

REPRODUCTION AND STAND ESTABLISHMENT

Red pine has far more exact requirements for establishment than jack pine. For example, red pine seed production is erratic; "bumper cone crops are produced only once every 10 or 12 years" (17). In addition, red pine cones are easily destroyed by crown fires, while jack pine's serotinous cones open and disperse seed after fire (1).

Requirements

Regeneration of red pine requires a combination of "... good seed production, seedbed preparation, and favorable precipitation during germination and seedling establishment" (3). Seed production, which is best in 50- to 150-year-old trees with good seed crops every 3 to 7 years (17), is mainly outside our control. We certainly have no influence over future precipitation to make it favorable for germination and establishment. Therefore, the only control we have is over seedbed preparation.

Seedbed Preparation

Red pine seeds require close contact with mineral soil to germinate. After establishment, red pine does not grow rapidly at first. It is relatively intolerant and will not survive in a pre-existing stand (30). Ahlgren (1) found that red pine needs about 3 postfire years of freedom from competing vegetation to dominate a site.

Fire can create relatively bare ground and eliminate competition. For example, in Ontario, areas that had undergone prescribed burns produced many more red pine seedlings than did unburned areas (38). In addition,

- sufficient duff was removed when its moisture content was about 60 percent or less (meaning burning must be done in summer);
- undesirable hardwoods were controlled by two consecutive annual fires;
- good 10-year-growth of red pine seedlings occurred only without an overstory (seeds must come from adjacent stands, shelterwood, and/or artificial seeding);
- the higher the fire intensity, the better the site preparation and hence the pine regeneration (39).

ESTABLISHED STANDS

Young Stands Vulnerable

Fire can devastate young red pine stands. Young, densely planted stands have been called the "... most flammable pure stand(s) of any northeastern tree species ..." (39). This is due to the well-aerated litter layer under a young pine stand and the continuous crown structure, which is well suited to crown fire. Flaky bark also helps a fire jump into the crown.

Increase Growth

In some instances, prescribed burning may increase the growth of established red pine stands. In Connecticut, red pine on sandy soil grew in height and volume, although not in diameter, throughout 20 years of annual burning, but unburned stands did not. The increases were thought to be due to increased pH as well as available phosphorus and exchangeable calcium (25).

Control Pests

Where natural seeding is important in the Lake States, the red pine cone beetle can be reduced with low intensity fires carried out between October 22 and May 10 (28). Judicious use of fire might also limit other pests. For instance, hare and mice could be deterred by eliminating understory cover. Burning might also curtail sweetfern on sites where this alternate host for the spittlebug is present. Although duff could be reduced to lessen the impact of the pine root collar weevil, this might require fire behavior destructive to red pine.

Control Vegetation

Fire can control undesirable understory species such as balsam fir. In Ontario, Methven and Murray (27) used fires of low intensity to kill balsam fir saplings, which were easily girdled by "gentle" surface fires. However, more than one such burn may be required to kill balsam fir understory.[1]

SUMMARY AND MANAGEMENT IMPLICATIONS

Fire in the Past

Red pine, because of its good growth characteristics, high productivity (24), and versatile wood (33), has been a favored species in the Lake States since the last century when Europeans found more than 7-million acres of these trees (33). The desire to regenerate today's red pine stands has stimulated an interest in how natural stands developed. Fire has been identified as a part of past natural red pine systems. Table 1 summarizes some findings about the use of fire in red pine stands.

Table 1.—Summary of fire use in red pine

Objectives	Location	Conditions	Fire behavior	Reference
Natural regeneration (duff removal)	Ontario	Moisture content of litter—60%	High intensity	(38)
Seedbed preparation (competition removal)	North Central States	Summer fires in slash soon after harvest (one or more fires)	Hot	(2)
Hardwood control	Ontario	Two consecutive summer burns	Gentle	(38)
Hardwood control (hazel)	Minnesota	Moisture content of humus—37-40%, summer fires	--	(8 and 9)
Balsam fir control	Ontario	Fire Weather Index 14-19[1]	Gentle	(27)
Understory fuel reduction (wildlife food increase)	North Central States	Periodic underburning	--	(2)
Red pine cone beetle reduction litter layer consumed or scorched no patch of ground to be unburned burning done while beetles on floor	Lake States	Burning Index[2] 11-41, Spread Index--8-31	Low intensities —back fire or strip head fire	(28)

[1] Fire Weather Index—a Canadian numerical rating of potential fire intensity (12). It is based on the effects of rainfall, relative humidity, windspeed, and temperature on fine fuels and duff.

[2] Burning Index and Spread Index are from the National Fire-Danger Rating System (15). The Burning Index is related to the amount of effort needed to contain a fire. The Spread Index is related to the forward rate of spread of a fire.

Regeneration

Van Wagner (39) suggests that fire should be reintroduced into natural red pine stands only in areas that will allow a maximum range of fire intensities. This would enable the fire(s) to remove duff, control hardwood brush, and remove overhead canopy in patches. These small areas would be prepared for regeneration, and in the interspersed patches, large red pine would have to remain as seed sources. On the other hand, Ahlgren (1) concludes that because human-induced change has taken place in most natural red pine stands, fire (prescribed or "natural") may be one of several alternatives for regenerating red pine.

Use of Fire

In summary, fire can have a place in red pine management. In addition to its previously described silvicultural role, fire can help maintain "parklike" stands (2). In areas valued for recreation, fire can make a stand more accessible as well as more visually pleasing. Also, frequent (5- to 10-year intervals), low intensity fires may kill aerial portions of any hardwood vegetation and thus promote low coppice growth, which would provide wildlife browse.

Obstacles

Although fire in red pine has many uses, it is not currently applied with any regularity. The limited number of days when fire weather is conducive to burning is a major physical obstacle to rapid expansion of prescribed burning in red pine (10). For example, during the spring in lower Michigan, fire weather appropriate for prescribed burning rarely lasts more than 1 day (36).

In addition to this physical limitation, there are also attitudinal obstacles, e.g., memories of recent and historical destructive fires such as the Mack Lake Fire in Michigan (36); organizational biases, e.g., managers trained to control fire rather than use it; and the widespread acceptance of other methods, e.g., chemical, mechanical, and silvicultural techniques (10). The large acreage of red pine plantations is a monument to these methods.

Prediction is Difficult

Research about fire's place and use in red pine has provided much information but no universal answers. Results of burning on one area are often not repeatable on another. As more site-specific information is collected, managers can gain confidence in prescribed burns, and burning will be viewed as an accepted management practice, especially for site preparation.

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Fire and red pine are closely associated. Fires can provide red pine with the mineral soil and freedom from competition it needs to become well established. Fire can also be used to control pests, increase tree growth, enhance aesthetics, and improve wildlife habitat.

KEY WORDS: *Pinus resinosa*, ecology, fire management, silviculture.

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General Technical Report NC-130

Wisconsin's Forest Statistics, 1987: An Inventory Update

W. Brad Smith and Jerold T. Hahn

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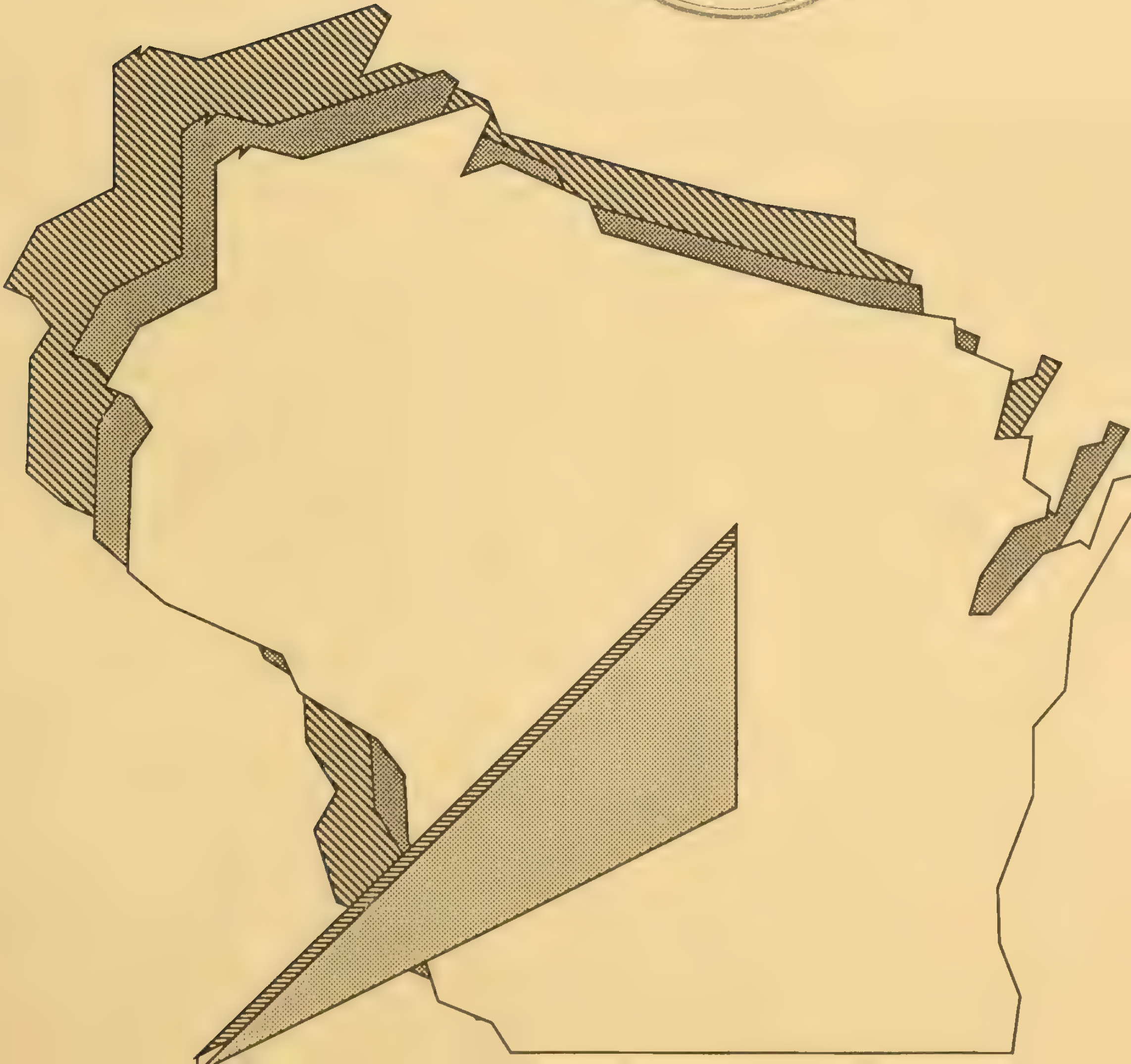

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Foreword

Forest Inventory and Analysis (FIA) is a continuing endeavor as mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974, which was preceded by the McSweeney-McNary Forest Research Act of 1928. The objective of FIA is to periodically inventory the Nation's forest land to determine its extent, condition, and volume of timber, growth, and depletions. Up-to-date resource information is essential for framing intelligent forest policies and programs. USDA Forest Service regional experiment stations are responsible for conducting these inventories and publishing summary reports for individual States. The North Central Forest Experiment Station is responsible for Forest Inventory and Analysis work in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin.

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Wisconsin's Forest Statistics, 1987: An Inventory Update

W. Brad Smith and Jerold T. Hahn

Update Highlights

Timberland

- Timberland area declined from 14.8 million acres in 1983 to 14.7 million acres in 1987, a loss of less than 1 percent.

- Maple-basswood is still the dominant forest type with 4.0 million acres or 27 percent of Wisconsin's 1987 timberland area.

- The area of jack pine forest type declined 3.1 percent to 530,000 acres as the passive management of this type took its toll.

- Red pine is still the most popular plantation species as shown by the 22,000-acre gain in the red pine forest type since 1983.

Timber Volume

- Growing-stock volume in 1987 is 16.5 billion cubic feet, 7 percent higher than the 15.4 billion cubic feet reported in 1983.

- Average growing-stock volume per acre in 1987 was 1,120 cubic feet, compared with 1,046 cubic feet in 1983.

- Sawtimber volume totaled 39.5 billion board feet in 1987, up 13 percent from 1983.

Net Growth

- Annual net growth increased from 33 cubic feet per acre per year in 1982 to 39 cubic feet in 1986.

- Mortality declined from 1.0 percent of inventory in 1982 to 0.6 percent in 1986. Much of the decline is attributed to increased management reflected by the update.

The growth processor used in this study does not accommodate catastrophic mortality. Therefore, the volume estimate of balsam fir and elm could be overstated in this report. However, because of the decline in Dutch elm disease and the spruce budworm population, we feel that the volume estimates presented for these species are usable as printed.

Removals

- Growing-stock removals have risen sharply since 1982, climbing from 285 million cubic feet to 329 million cubic feet annually in 1986. Major industrial expansion in the waferboard and pulp industry in northern Wisconsin is primarily responsible for the increase.

- Aspen growth and removals in Wisconsin have reached parity. As older unmanaged stands of aspen convert to more tolerant forest types, losses in aspen species have occurred.

Biomass

- Tree biomass totaled 948 million green tons in 1987. Of this volume, 74 percent is in growing-stock trees, 13 percent is in cull trees, and 13 percent is in trees less than 5 inches d.b.h.

- The average green weight per cubic foot (including bark) for softwood species was 45 pounds; the average for hardwoods was 53 pounds.

W. Brad Smith and **Jerold T. Hahn** are Principal Mensurationists with the North Central Forest Experiment Station, St. Paul, MN.

Background

Tree growth models developed at the North Central Forest Experiment Station have made it possible for the Forest Inventory and Analysis (FIA) work unit to update inventory data to estimate the current resource. The purpose of this report is to present updated statistics for the State of Wisconsin that will be used for the 1990 assessment required by the Forest and Rangeland Renewable Resources Planning Act of 1974. The tables provide data by forest survey unit (fig. 1) and represent the timberland base as of January 1, 1987. The term "update," as it is used here, is an estimate of current forest statistics derived by modeling the dynamic change in a forest from a known time in the past. The major components of this change are land change, growth, mortality, regeneration, and removals.

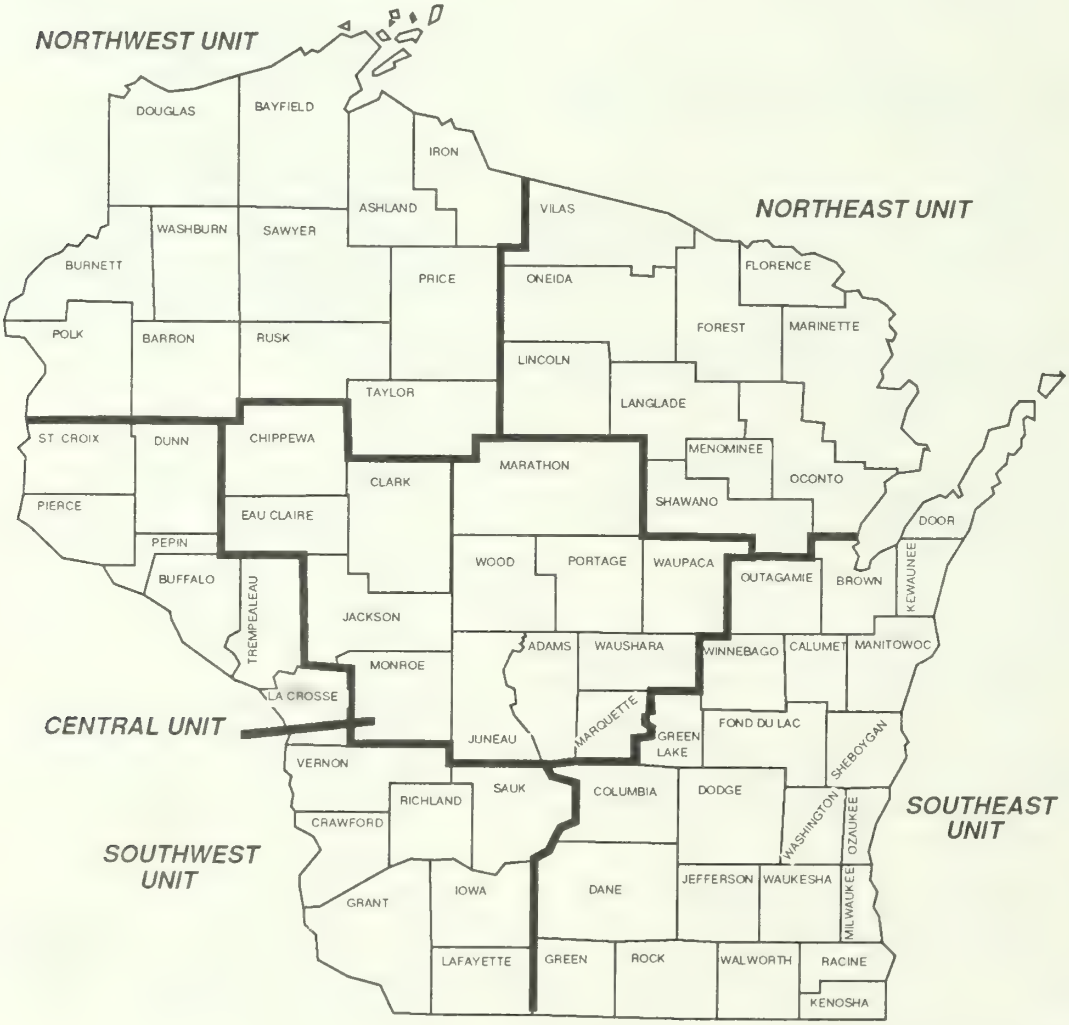

Figure 1.--*Forest inventory units in Wisconsin.*

Methodology

Land Base Change

The basic sample design used by FIA in the North Central Region is a two-phase sample consisting of (1) a photo sample to estimate forest-nonforest area and (2) a ground phase, which is a subsample of the photo sample, to provide information about the volume and condition of the forest.

New photo work for the entire region would be too costly and time consuming with current technology. However, we've found that for update periods of 10 years or less, area change at the State level can be estimated using trend analysis and by gathering information from local resource managers. These data then provide the first-phase area factors to be applied to the updated plots.

We assumed timberland area for public and industry ownerships was stable during the update period. For all other ownerships a modest annual decline of about 0.1 percent was assumed, which reflects the view of resource managers that urbanization and agricultural expansion have not seriously eroded the timberland base of the region.

The objectives of the diverse group of owners that hold Wisconsin's forest land play a significant role in the stability of the timberland base. Knowledge of these objectives is essential to strategic forest planning. Public agencies are mandated by law to provide detailed information about management plans that outline the policies and programs designed to ensure a viable forest resource into the future.

The timberland area figures presented here represent the most recent data available when the update was processed. The reader is cautioned to contact the appropriate public agency to verify or update area figures for any analysis that may be sensitive to local changes in the timberland base, such as recently designated reserved or deferred forest land. Area and volume figures would have to be adjusted accordingly for any ownerships affected by significant changes in the timberland base.

Additional information is available about nonindustrial private owners and their objectives in the University of Wisconsin Cooperative Extension Report, "The Wisconsin Private Woodland Owner: A Profile" (Roberts *et al.* 1986).

Growth and Mortality

We used the Stand and Tree Evaluation and Modeling System (STEMS) (Belcher 1981) to update 7,155 forest inventory plots from the 1983 field survey to the year 1987. STEMS is a distance-independent, individual tree growth model designed to simulate tree growth and mortality for a diverse range of forest conditions.

Growth and mortality functions were calibrated and validated with data from throughout the Lake States (Buchman 1983, Holdaway and Brand 1983,1985). Test projections over a range of forest conditions produced reliable results when compared with remeasurement data from the Lake States. Adjustment factors derived from recent remeasurement data in the Lake States were used to fine tune the model and improve precision (Holdaway 1985).

Regenereation

Although STEMS regeneration routines for the Lake States had not been fully developed at the time of the update, the outcome was not significantly affected. Most trees that became established on harvested land or in seedling stands at the beginning of the update would not have grown to merchantable size by the end of the 4-year period. Biomass figures in table 19 for trees under 5 inches in diameter will be conservative due to inability of the model to introduce trees to the 1-inch diameter class.

Removals

Removals data were derived by trend analysis using periodic pulpwood (Blyth and Smith 1985), saw log (Blyth *et al.* 1985), and veneer (Blyth and Smith 1984) production reports and base year data for all removals provided in the 1983 Wisconsin report (Raile 1985). Removals attributed to loss of timberland were made by adjusting plot expansion factors to arrive at a specified set of current area figures by forest type. Estimates of timber removals in the Lake States are reviewed in more detail in the article, "Tracking Timber Demand in the Lake States" (Smith and Blyth 1986).

The Lake States version of STEMS was modified to simulate actual removals. Computerized management guides (Brand 1981) were used to select a subset of inventory plots that were eligible for silvicultural treatment during the update period.

These guides were used in lieu of detailed information on Wisconsin management strategies. A special removals algorithm scanned each selected plot to determine if it would be cut. The volume from cut plots was accumulated until the estimated volume of growing-stock removals by species was reached. Volume estimates were produced using volume equations developed for the Lake States (Hahn 1984 and Smith 1985).

All area and volume figures for the update were reviewed by personnel from the Wisconsin Department of Natural Resources, the National Forest System, industry resource managers, and other private individuals to assure reasonableness and consistency. A more detailed description of the methodology will be presented later in a publication on inventory updating procedures in the North Central Region.

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Appendix

Tree Species Groups in Wisconsin[1]

SOFTWOODS	
Eastern white pine	*Pinus strobus*
Red pine	*Pinus resinosa*
Jack pine	*Pinus banksiana*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea*
Tamarack	*Larix laricina*
Northern white-cedar	*Thuja occidentalis*
Other softwoods	
Norway spruce	*Picea abies*
Scotch pine	*Pinus sylvestris*
HARDWOODS	
White oak	
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Bur oak	*Quercus macrocarpa*
Select red oak	
Northern red oak	*Quercus rubra*
Other red oak	
Northern pin oak	*Quercus ellipsoidalis*
Black oak	*Quercus velutina*
Select hickory	
Shagbark hickory	*Carya ovata*
Other hickory	
Pignut hickory	*Carya glabra*
Bitternut hickory	*Carya cordiformis*
Hard maple	
Sugar maple	*Acer saccharum*
Black maple	*Acer nigrum*
Soft maple	
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
American beech	*Fagus grandifolia*
Yellow birch	*Betula alleghaniensis*
Black ash	*Fraxinus nigra*
White and green ash	
White ash	*Fraxinus americana*
Green ash	*Fraxinus pennsylvanica*
Balsam poplar	*Populus balsamifera*
Eastern cottonwood	*Populus deltoides*
Black willow	*Salix nigra*
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Basswood	*Tilia americana*
Black walnut	*Juglans nigra*
Black cherry	*Prunus serotina*
Butternut	*Juglans cinerea*
Elm	
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*
Rock elm	*Ulmus thomasii*
Paper birch	*Betula papyrifera*
River birch	*Betula nigra*
Other hardwoods	
Boxelder	*Acer negundo*
Hackberry	*Celtis occidentalis*
Black locust	*Robinia pseudoacacia*
Honey locust	*Gleditsia tryacanthos*
Red mulberry	*Morus rubra*
Northern catalpa	*Catalpa speciosa*

Metric Equivalents of Units Used in This Report

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.

Definitions

Acceptable trees.—Growing-stock trees of commercial species that meet specified standards of size and quality.

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Biomass.—The total above-ground weight, excluding foliage, of all live trees reported in green tons. Biomass is made up of 5 components:

Growing-stock bole and stump.—Biomass of a growing-stock tree from ground level to a 4-inch top.

Growing-stock top and limbs.—Biomass of a growing-stock tree above a 4-inch top and all limbs below the 4-inch top.

Cull bole and stump.—Biomass of a cull tree from ground level to a 4-inch top.

Cull top and limbs.—Biomass of a cull tree above a 4-inch top and all limbs below the 4-inch top.

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[1] *The common and scientific names are based on Little, Elbert L. 1979. Checklist of United States trees (native and naturalized). Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service. 375 p.*

1- to 5-inch trees.—Above ground biomass of all live trees 1- to 5-inches in diameter at breast height.

Commercial species.—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

County and municipal land.—Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

Cropland.—Land under cultivation within the past 24 months; including cropland harvested, crop failures, cultivated summer fallow, idle cropland used only for pasture, orchards, and land in soil improvement crops, but excluding land cultivated in developing improved pasture.

Cull.—Portions of a tree that are unusable for industrial wood products because of rot, form, or other defect.

Diameter classes.—A classification of trees based on diameter outside bark, measured at breast height (4.5 feet above the ground). (Note: d.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Survey, with the even inch the approximate mid-point for a class. For example, the 6-inch class includes trees 5.0 through 6.9 inches d.b.h.)

Farm.—Any place from which $1,000 or more of Agricultural products were produced and sold during the year.

Farmer-owned land.—Land owned by farm operators. (Note: Excludes land leased by farm operators from nonfarm owners, such as railroad companies and States.)

Forest industry land.—Land owned by companies or individuals operating primary wood-using plants.

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note: Stocking is measured by comparison of basal area and/or number of trees, by age or size and spacing with specified standards.) The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas shall be classed as forest if less than 120 feet wide. Also see definitions for land area, timberland, nontimberland, reserved forest land, stocking, woodland, and water.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet tall at maturity.

Forest type.—A classification of forest land based on the species forming a plurality of live tree stocking. Major forest types are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, elm, and maple.)

Elm-ash-soft maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Maple-birch.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, and basswood.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Gross area.—The entire area of land and water as determined by the Bureau of the Census.

Growing-stock trees.—Live trees of commercial species qualifying as acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem. Cubic feet can be converted to cords by dividing by 79 cubic feet per solid wood cord.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Idle farmland.—Includes former cropland, orchards, improved pastures, and farm sites not tended within the past 2 years and presently less than 16.7 percent stocked with trees.

Improved pasture.—Land currently improved for grazing by cultivating, seeding, irrigating, or clearing of trees or brush and less than 16.7 percent stocked with live trees.

Indian land.—All lands held in trust by the United States for individual Indians or tribes, or all lands, titles to which are held by individual Indians or tribes, subject to Federal restrictions against alienation.

Industrial wood.—All roundwood products, except fuelwood.

Land area.—*Bureau of the Census.*—The area of dry land and land temporarily or partly covered by water such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs, estuaries, and canals less than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

Forest Inventory and Analysis.—The same as the Bureau of the Census, except minimum width of streams, etc., is 120 feet and minimum size of lakes, etc., is 1 acre.

Live trees.—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

Marsh.—Nonforest land that characteristically supports low, generally herbaceous or shrubby vegetation and that is intermittently covered with water.

Merchantable.—Refers to a pulpwood or saw log section that meets pulpwood or saw log specifications, respectively.

Miscellaneous federal land.—Federal land other than national forest.

Miscellaneous private land.—Privately owned land other than forest-industry and farmer-owned land.

Mortality.—The volume of sound wood in growing-stock and sawtimber trees that die annually.

National forest land.—Federal land that has been legally designated as national forest or purchase units, and other land administered by the USDA Forest Service.

Net annual growth of growing-stock.—The annual change in volume of sound wood in live sawtimber and poletimber trees and the total volume of trees entering these classes through ingrowth, less volume losses resulting from natural causes.

Net annual growth of sawtimber.—The annual change in the volume of live sawtimber trees and the total volume of trees reaching sawtimber size, less volume losses resulting from natural causes.

Net volume.—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial wood products.

Nonforest land.—Land that has never supported forests, and land formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide and more than 1 acre in area to qualify as nonforest land.)

a. *Nonforest land without trees*.—Nonforest land with no live trees present.

b. *Nonforest land with trees*.—Nonforest land with one or more trees per acre at least 5 inches d.b.h.

Nonstocked land.—Timberland less than 16.7 percent stocked with growing-stock trees.

Nontimberland.—(a) Woodland and (b) reserved forest land.

Other removals.—Growing-stock trees removed but not utilized for products, or trees left standing but "removed" from the timberland classification by land use change. Examples are removals from cultural operations such as timber stand improvement work, land clearing, and changes in land use.

Ownership.—Property owned by one owner, regardless of the number of parcels in a specified area.

Pasture and range.—Land which is currently improved for grazing by cultivation seeding or irrigation plus land on which the natural plant cover is composed principally of native grasses, forbs, or shrubs valuable for forage.

Physiographic class.—A measure of soil and water conditions that affect tree growth on a site. The physiographic classes are:

Xeric sites.—Very dry soils where excessive drainage seriously limits both growth and species occurrence. Example: sandy jack pine plains.

Xeromesic sites.—Moderately dry soils where excessive drainage limits growth and species occurrence to some extent. Example: dry oak ridge.

Mesic sites.—Deep, well-drained soils. Growth and species occurrence are limited only by climate.

Hydromesic sites.—Moderately wet soils where insufficient drainage or infrequent flooding limits growth and species occurrence to some extent. Example: better drained bottomland hardwood sites.

Hydric sites.—Very wet sites where excess water seriously limits both growth and species occurrence. Example: frequently flooded river bottoms and spruce bogs.

Poletimber stands.—(See stand-size class.)

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber size.

Reserved forest land.—Forest land sufficiently productive to qualify as timberland but withdrawn from timber utilization through statute, administrative regulation, designation, or exclusive use for Christmas tree production, as indicated by annual shearing.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of extra cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Salvable dead trees.—Standing or down dead trees that are considered merchantable by regional standards.

Saplings.—Live trees 1 to 5 inches d.b.h.

Sapling-seedling stands.—(See stand-size class.)

Saw log.—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by regional standards.

Saw log portion.—That part of the bole of sawtimber trees between the stump and the saw log top.

Saw log top.—The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for soft- woods and 9 inches d.o.b. for hardwoods.

Sawtimber stands.—(See stand-size class.)

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting regional specifications for freedom from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

Sawtimber volume.—Net volume of the saw log portion of live sawtimber in board feet, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Seedlings.—Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

Short-log (rough tree).—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Site class.—A classification of forest land in terms of inherent capacity to grow crops of industrial wood based on fully stocked natural stands.

Site index.—An expression of forest site quality based on the total height of free-growing dominant or codominant trees of a representative species in the forest type at age 50.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.—The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

Stand-size class.—A classification of forest land based on the size class of all live trees; that is, sawtimber, poletimber of seedlings and saplings. Only those types contributing to no more than 16 percent stocking at a point will be used to determine stand-size class. Remember that stands with less than 16.7 percent stocking in growing stock trees will be classified as nonstocked. Noncommercial trees are not used for determining stand-size classes.

Sawtimber stands.—Stands with at least half of the all live stocking in sawtimber and poletimber trees and with the sawtimber stocking equal to or larger than the poletimber stocking.

Poletimber stands.—Stands with at least half of the all live stocking in poletimber and sawtimber trees and with the poletimber stocking larger than the sawtimber stocking.

Sapling-seedling stands.—Stands with more than half of the all live stocking in saplings and/or seedlings.

State land.—Land owned by States, or land leased to these governmental units for 50 years or more.

Stocking.—The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard. A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h. Stands are grouped into the following stocking classes:

Overstocked stands.—Stands in which stocking of trees is 134.0 percent or more.

Fully stocked stands.—Stands in which stocking of trees is from 101.0 to 133.9 percent.

Medium stocked stands.—Stands in which stocking of trees is from 61.0 to 100.9 percent.

Poorly stocked stands.—Stands in which stocking of trees is from 16.7 to 60.9 percent.

Nonstocked areas.—Timberland on which stocking of trees is less than 16.7 percent.

Timber removals from growing stock.—The volume of sound wood in live sawtimber and poletimber trees removed annually for forest products (including roundwood products and logging residues) and for other removals. Roundwood products are logs, bolts, or other round sections cut from trees. Logging residues are the unused portions of cut trees plus unused trees killed by logging. Other removals are growing-stock trees removed by cultural operations such as timber stand improvement work, and by land clearing and changes in land use.

Timber removals from sawtimber.—The net board-foot volume of live sawtimber trees removed for forest products annually (including roundwood products and logging residues) and for other removals.

Timberland.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for producing industrial wood in the foreseeable future.) Also see definition of pastured timberland

Tree biomass.—The total aboveground weight (including the bark) of all live trees.

Tree size class.—A classification of trees based on diameter at breast height, including sawtimber trees, poletimber trees, saplings, and seedlings.

Upper stem portion.—That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Urban and other areas.—Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; powerlines; and other rights-of-way; or other nonforest land not included in any other specified land use class.

Water.—*Bureau of the Census.*—Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 40 acres or more of area; streams, sloughs, estuaries, and canals one-eighth of a statute mile or more in width.

Noncensus.—Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 1-39.9 acres of area; streams, sloughs, estuaries, and canals 120 feet to one-eighth of a statute mile in width.

Windbreak.—A group of trees less than 120 feet wide used for the protection of soil, cropfields, and buildings in use.

Wooded pasture.—Improved pasture with more than 16.7 percent stocking in live trees but less than 25 percent stocking in growing-stock trees. Area is currently improved for grazing or there is other evidence of grazing.

Wooded strip.—An acre or more of natural continuous forest land that would otherwise meet survey standards for timberland except that it is less than 120 feet wide.

Woodland.—Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soils, dry climate, poor drainage, high elevation, steepness, and rockiness.)

Table Titles

Table 1.—Area of land by land use class and Forest Survey Unit, 1983 and 1987

Table 2.—Area of timberland by ownership class and Forest Survey Unit

Table 3.—Area of timberland by forest type, stand-age class, and Forest Survey Unit

Table 4.—Area of timberland by forest type, site-index class, and Forest Survey Unit

Table 5.—Area of timberland by forest type, stand-size class, and Forest Survey Unit

Table 6.—Net volume of growing stock on timberland, by forest type, stand-age class, and Forest Survey Unit

Table 7.—Net volume of sawtimber on timberland, by forest type, stand-age class, and Forest Survey Unit

Table 8.—Growing-stock volume and periodic growth on timberland by forest type, component of growth, and Forest Survey Unit

Table 9.—Growing-stock volume and periodic growth on timberland by species group, component of growth, and Forest Survey Unit

Table 10.—Sawtimber volume and periodic growth on timberland by forest type and component of growth

Table 11.—Sawtimber volume and periodic growth on timberland by species group and component of growth

Table 12.—Net volume of growing stock on timberland by species group and forest type

Table 13.—Net volume of sawtimber on timberland by species group and forest type

Table 14.—Net volume of growing stock on timberland by species group and diameter class

Table 15.—Net volume of sawtimber on timberland by species group and diameter class

Table 16.—Annual net growth mortality and removals of growing stock and sawtimber on timberland by softwoods and hardwoods

Table 17.—Net volume of short-log trees on timberland by species group and diameter class (cubic feet)

Table 18.—Net volume of short-log trees on timberland by species group and diameter class (board feet)

Table 19.—All live tree biomass on timberland by species group and tree biomass component

Table 1.--Area of land by land class, Wisconsin, 1983 and 1987

(In thousand acres)

Land class	All units		Forest survey unit									
			Northeast		Northwest		Central		Southwest		Southeast	
	1983	1987	1983	1987	1983	1987	1983	1987	1983	1987	1983	1987
Forest land												
Timberland												
Jack pine	546.5	529.8	81.7	76.3	247.8	242.6	203.1	198.0	11.2	10.2	2.7	2.7
Red pine	478.2	500.4	157.8	164.7	132.6	136.8	135.5	141.6	40.1	43.1	12.2	14.2
White pine	225.6	230.3	81.1	82.9	36.5	34.6	77.9	78.7	13.7	15.8	16.4	18.3
Balsam fir	419.4	401.4	187.9	177.5	219.6	212.0	11.9	11.9	-	-	-	-
White spruce	61.4	61.4	19.8	19.8	31.9	31.9	2.2	2.2	2.5	2.5	5.0	5.0
Black spruce	273.0	277.3	147.5	150.2	111.2	112.8	11.6	11.6	-	-	2.7	2.7
Northern white-cedar	370.7	380.4	186.0	189.8	107.8	110.6	23.3	25.3	-	-	53.6	54.7
Tamarack	222.7	219.0	63.0	60.1	111.5	111.5	39.0	38.2	-	-	9.2	9.2
Oak-hickory	2,858.7	2,847.6	149.3	143.8	415.6	410.9	937.6	935.9	1,063.4	1,061.5	292.8	295.5
Elm-ash-soft maple	1,240.6	1,224.0	235.9	226.1	414.9	412.1	271.5	269.8	117.8	115.5	200.5	200.5
Maple-basswood	3,996.9	4,017.3	1,280.2	1,295.4	1,478.7	1,487.7	506.2	509.6	497.9	495.6	233.9	229.0
Aspen	3,261.5	3,226.3	1,026.7	1,017.5	1,508.3	1,498.9	577.5	569.1	85.7	82.7	63.3	58.1
Paper birch	641.6	648.5	191.5	196.3	268.8	271.5	118.6	120.5	54.4	53.7	8.3	6.5
Exotic	2.2	2.2	-	-	-	-	2.2	2.2	-	-	-	-
Nonstocked	160.4	160.4	20.1	20.1	65.6	65.6	32.8	32.8	33.3	33.3	8.6	8.6
Subtotal	14,759.4	14,726.3	3,828.5	3,820.5	5,150.8	5,139.5	2,950.9	2,947.4	1,920.0	1,913.9	909.2	905.0
Woodland	331.0	331.0	140.8	140.8	165.8	165.8	21.5	21.5	-	-	2.9	2.9
Reserved	260.9	260.9	52.0	52.0	114.6	114.6	30.1	30.1	38.8	38.8	25.4	25.4
Total	15,351.3	15,318.2	4,021.3	4,013.3	5,431.2	5,419.9	3,002.5	2,999.0	1,958.8	1,952.7	937.5	933.3
Nonforest land												
Cropland	12,712.4	12,743.2	748.6	756.2	1,272.3	1,282.3	2,441.0	2,444.5	2,902.6	2,908.7	5,347.9	5,351.5
Pasture and range	2,128.7	2,128.7	209.3	209.3	345.4	345.4	538.7	538.7	712.5	712.5	322.8	322.8
Other	4,640.4	4,642.7	721.0	721.4	876.5	877.8	1,188.0	1,188.0	576.6	576.6	1,278.3	1,278.9
Total	19,481.5	19,514.6	1,678.9	1,686.9	2,494.2	2,505.5	4,167.7	4,171.2	4,191.7	4,197.8	6,949.0	6,953.2
Total land	34,832.8	34,832.8	5,700.2	5,700.2	7,925.4	7,925.4	7,170.2	7,170.2	6,150.5	6,150.5	7,886.5	7,886.5
Water (Bureau of Census)	1,105.0	1,105.0	262.8	262.8	290.3	290.3	114.6	114.6	126.0	126.0	311.3	311.3
Total land and water	35,937.8	35,937.8	5,963.0	5,963.0	8,215.7	8,215.7	7,284.8	7,284.8	6,276.5	6,276.5	8,197.8	8,197.8

Table 2.--Area of timberland by ownership class and Forest Survey Unit, Wisconsin, 1987

(In thousand acres)

Ownership class	All units	Forest survey unit				
		Northeast	Northwest	Central	Southwest	Southeast
National forest	1,242.3	548.8	693.5	-	-	-
Miscellaneous fed.	177.0	3.9	7.3	131.4	29.8	4.6
State	569.5	193.5	177.1	96.6	34.8	67.5
County and municipal	2,178.7	645.6	1,109.7	399.6	10.9	12.9
Indian	354.7	255.5	94.6	4.6	-	-
Forest industry	1,158.8	486.8	528.9	127.6	-	15.5
Farmer	3,496.4	380.5	445.6	994.9	1,248.8	426.6
Misc. private-corp.	663.0	161.9	223.0	129.0	93.0	56.1
Misc. private-indiv.	4,885.9	1,144.0	1,859.8	1,063.7	496.6	321.8
All owners	14,726.3	3,820.5	5,139.5	2,947.4	1,913.9	905.0

Table 3.--Area of timberland by forest type, stand-age class, and Forest Survey Unit, Wisconsin, 1987

(In thousand acres)

ALL UNITS

Forest type	All ages	Stand-age class(years)									
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	529.8	150.6	71.4	112.5	137.0	47.6	3.3	5.5	1.9	-	-
Red pine	500.4	183.4	107.9	97.3	54.6	21.4	7.3	7.8	17.5	3.2	-
White pine	230.3	37.8	11.2	18.6	23.1	21.6	24.7	27.3	35.9	9.9	20.2
Balsam fir	401.4	75.6	42.2	47.3	47.0	96.6	49.6	13.2	15.9	7.3	6.7
White spruce	61.4	19.8	10.7	13.9	6.5	8.5	2.0	-	-	-	-
Black spruce	277.3	72.1	72.4	36.4	28.3	14.4	14.4	24.9	12.5	-	1.9
Northern white-cedar	380.4	24.7	18.8	8.0	49.2	34.5	39.6	30.8	97.8	31.3	45.7
Tamarack	219.0	70.0	39.2	13.6	21.4	16.5	18.9	15.6	16.5	3.7	3.6
Oak-hickory	2,847.6	489.0	95.6	122.6	335.8	421.2	273.3	281.9	416.9	174.8	236.5
Elm-ash-soft maple	1,224.0	246.6	85.2	117.1	158.1	121.8	130.9	128.3	147.1	49.7	39.2
Maple-basswood	4,017.3	581.0	233.4	259.6	617.2	685.4	482.3	242.4	443.2	216.1	256.7
Aspen	3,226.3	1,194.6	306.6	466.0	693.6	341.5	129.0	56.7	38.3	-	-
Paper birch	648.5	114.6	60.9	95.5	150.2	132.1	77.3	13.8	0.3	3.8	-
Exotic	2.2	2.2	-	-	-	-	-	-	-	-	-
Nonstocked	160.4	160.4	-	-	-	-	-	-	-	-	-
All types	14,726.3	3,422.4	1,155.5	1,408.4	2,322.0	1,963.1	1,252.6	848.2	1,243.8	499.8	610.5

NORTHEAST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	76.3	15.1	10.0	20.9	11.4	17.4	1.5	-	-	-	-
Red pine	164.7	38.1	27.0	50.4	25.4	3.3	5.3	3.2	8.8	3.2	-
White pine	82.9	7.1	6.9	6.9	5.4	12.3	1.9	12.4	13.3	3.7	13.0
Balsam fir	177.5	37.3	18.3	25.7	18.4	39.7	15.7	9.9	5.5	3.5	3.5
White spruce	19.8	8.6	-	-	2.7	8.5	-	-	-	-	-
Black spruce	150.2	35.8	39.6	11.1	10.4	10.4	12.6	19.5	8.9	-	1.9
Northern white-cedar	189.8	14.1	13.3	1.7	22.5	13.2	19.1	12.7	51.7	17.7	23.8
Tamarack	60.1	13.0	17.4	1.8	-	6.6	12.7	3.4	3.4	1.8	-
Oak-hickory	143.8	26.0	3.4	3.5	21.4	34.5	15.0	17.6	13.3	5.5	3.6
Elm-ash-soft maple	226.1	36.3	15.7	23.1	28.3	17.5	42.7	21.4	28.5	3.7	8.9
Maple-basswood	1,295.4	123.0	50.4	80.1	231.1	229.2	160.2	70.6	117.6	83.4	149.8
Aspen	1,017.5	430.1	72.1	129.1	193.4	115.0	50.4	12.4	15.0	-	-
Paper birch	196.3	22.2	20.2	14.5	47.8	51.9	31.8	7.6	0.3	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	20.1	20.1	-	-	-	-	-	-	-	-	-
All types	3,820.5	826.8	294.3	368.8	618.2	559.5	368.9	190.7	266.3	122.5	204.5

NORTHWEST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	242.6	50.2	33.4	49.5	80.6	21.8	1.8	3.4	1.9	-	-
Red pine	136.8	54.5	10.7	22.9	24.7	10.9	2.0	4.6	6.5	-	-
White pine	34.6	-	-	-	3.1	4.7	11.2	10.4	3.6	1.6	-
Balsam fir	212.0	31.1	21.5	21.6	26.3	56.9	33.9	3.3	10.4	3.8	3.2
White spruce	31.9	3.7	10.7	11.7	3.8	-	2.0	-	-	-	-
Black spruce	112.8	24.4	32.8	25.3	15.5	4.0	1.8	5.4	3.6	-	-
Northern white-cedar	110.6	1.8	5.5	0.7	21.1	4.0	15.0	10.1	27.7	5.5	19.2
Tamarack	111.5	34.6	21.8	7.0	16.8	5.4	1.7	7.7	11.0	1.9	3.6
Oak-hickory	410.9	111.7	11.0	18.0	44.5	105.1	30.8	34.9	35.3	15.0	4.6
Elm-ash-soft maple	412.1	62.3	33.3	36.0	55.8	48.7	44.3	36.2	53.7	18.6	23.2
Maple-basswood	1,487.7	154.9	84.6	91.9	300.8	324.9	218.5	91.8	128.9	45.8	45.6
Aspen	1,498.9	495.7	157.4	229.2	345.2	172.3	66.2	24.0	8.9	-	-
Paper birch	271.5	33.7	25.6	44.3	77.4	52.0	30.9	3.8	-	3.8	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	65.6	65.6	-	-	-	-	-	-	-	-	-
All types	5,139.5	1,124.2	448.3	558.1	1,015.6	810.7	460.1	235.6	291.5	96.0	99.4

(Table 3 continued on next page)

(Table 3 continued)

CENTRAL

Forest type	All ages	Stand-age class(years)									
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	198.0	80.3	28.0	37.1	42.1	8.4	-	2.1	-	-	-
Red pine	141.6	57.4	54.4	15.9	4.5	7.2	-	-	2.2	-	-
White pine	78.7	9.1	-	11.7	9.1	4.6	11.6	4.5	16.3	4.6	7.2
Balsam fir	11.9	7.2	2.4	-	2.3	-	-	-	-	-	-
White spruce	2.2	2.2	-	-	-	-	-	-	-	-	-
Black spruce	11.6	9.2	-	-	2.4	-	-	-	-	-	-
Northern white-cedar	25.3	-	-	-	-	12.3	2.7	5.3	5.0	-	-
Tamarack	38.2	19.9	-	2.5	2.3	4.5	2.4	4.5	2.1	-	-
Oak-hickory	935.9	185.7	41.2	57.3	138.7	162.8	119.1	110.5	77.4	11.8	31.4
Elm-ash-soft maple	269.8	79.3	2.2	25.2	37.4	23.4	20.8	35.0	35.1	9.0	2.4
Maple-basswood	509.6	130.3	31.3	28.5	45.8	54.9	61.3	39.5	77.9	21.0	19.1
Aspen	569.1	222.4	50.4	84.7	136.2	41.3	4.5	17.9	11.7	-	-
Paper birch	120.5	46.7	11.8	26.4	11.7	12.1	9.4	2.4	-	-	-
Exotic	2.2	2.2	-	-	-	-	-	-	-	-	-
Nonstocked	32.8	32.8	-	-	-	-	-	-	-	-	-
All types	2,947.4	884.7	221.7	289.3	432.5	331.5	231.8	221.7	227.7	46.4	60.1

SOUTHWEST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	10.2	5.0	-	2.3	2.9	-	-	-	-	-	-
Red pine	43.1	21.4	15.8	5.9	-	-	-	-	-	-	-
White pine	15.8	15.8	-	-	-	-	-	-	-	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	2.5	2.5	-	-	-	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	-	-	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-	-	-
Oak-hickory	1,061.5	139.7	32.0	36.2	115.6	92.5	96.9	85.6	236.7	113.4	112.9
Elm-ash-soft maple	115.5	32.0	5.6	5.6	8.7	16.7	8.1	11.3	16.9	10.6	-
Maple-basswood	495.6	129.8	47.0	43.3	29.2	46.5	18.9	17.7	81.4	53.3	28.5
Aspen	82.7	22.9	16.7	10.7	13.8	10.5	5.4	-	2.7	-	-
Paper birch	53.7	8.1	3.3	7.7	13.3	16.1	5.2	-	-	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	33.3	33.3	-	-	-	-	-	-	-	-	-
All types	1,913.9	410.5	120.4	111.7	183.5	182.3	134.5	114.6	337.7	177.3	141.4

SOUTHEAST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	2.7	-	-	2.7	-	-	-	-	-	-	-
Red pine	14.2	12.0	-	2.2	-	-	-	-	-	-	-
White pine	18.3	5.8	4.3	-	5.5	-	-	-	2.7	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	5.0	2.8	-	2.2	-	-	-	-	-	-	-
Black spruce	2.7	2.7	-	-	-	-	-	-	-	-	-
Northern white-cedar	54.7	8.8	-	5.6	5.6	5.0	2.8	2.7	13.4	8.1	2.7
Tamarack	9.2	2.5	-	2.3	2.3	-	2.1	-	-	-	-
Oak-hickory	295.5	25.9	8.0	7.6	15.6	26.3	11.5	33.3	54.2	29.1	84.0
Elm-ash-soft maple	200.5	36.7	28.4	27.2	27.9	15.5	15.0	24.4	12.9	7.8	4.7
Maple-basswood	229.0	43.0	20.1	15.8	10.3	29.9	23.4	22.8	37.4	12.6	13.7
Aspen	58.1	23.5	10.0	12.3	5.0	2.4	2.5	2.4	-	-	-
Paper birch	6.5	3.9	-	2.6	-	-	-	-	-	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	8.6	8.6	-	-	-	-	-	-	-	-	-
All types	905.0	176.2	70.8	80.5	72.2	79.1	57.3	85.6	120.6	57.6	105.1

Table 4.--Area of timberland by forest type, site-index class, and Forest Survey Unit, Wisconsin, 1987

(In thousand acres)

Forest type	All classes	Site-index class (feet)								
		11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
ALL UNITS										
Jack pine	529.8	-	1.6	8.1	70.3	168.0	198.3	71.7	10.0	1.8
Red pine	500.4	-	-	9.5	8.2	82.8	169.0	163.1	63.1	4.7
White pine	230.3	-	-	6.8	25.4	62.6	72.1	36.8	23.5	3.1
Balsam fir	401.4	3.2	6.7	43.5	106.6	109.9	100.4	21.0	8.3	1.8
White spruce	61.4	-	-	2.8	11.8	12.1	10.7	24.0	-	-
Black spruce	277.3	-	73.6	97.4	67.1	23.9	11.8	3.5	-	-
Northern white-cedar	380.4	6.9	119.2	100.1	75.9	43.6	30.0	2.7	2.0	-
Tamarack	219.0	-	19.7	45.3	52.0	50.1	42.0	5.9	4.0	-
Oak-hickory	2,847.6	-	-	127.1	391.9	791.9	742.2	510.0	221.1	63.4
Elm-ash-soft maple	1,224.0	-	7.2	74.7	189.6	347.0	299.7	184.5	100.3	21.0
Maple-basswood	4,017.3	-	-	40.3	253.8	894.1	1,323.2	1,000.6	418.3	87.0
Aspen	3,226.3	-	-	18.7	161.0	497.2	946.0	1,085.8	447.6	70.0
Paper birch	648.5	-	-	8.0	49.2	155.1	215.1	143.4	67.3	10.4
Exotic	2.2	-	-	-	-	-	-	2.2	-	-
Nonstocked	160.4	-	3.8	17.4	28.0	46.8	31.2	25.8	4.7	2.7
All types	14,726.3	10.1	231.8	599.7	1,490.8	3,285.1	4,191.7	3,281.0	1,370.2	265.9
NORTHEAST										
Jack pine	76.3	-	1.6	1.5	8.3	21.7	23.5	16.5	3.2	-
Red pine	164.7	-	-	-	3.6	31.1	56.0	54.1	19.9	-
White pine	82.9	-	-	1.8	10.4	20.1	27.1	12.7	10.8	-
Balsam fir	177.5	-	5.0	25.5	41.6	47.2	46.2	10.2	1.8	-
White spruce	19.8	-	-	-	5.4	8.3	-	6.1	-	-
Black spruce	150.2	-	39.0	47.4	37.9	15.4	7.0	3.5	-	-
Northern white-cedar	189.8	3.4	67.2	59.2	25.7	23.1	9.2	-	2.0	-
Tamarack	60.1	-	6.8	17.2	10.4	24.1	1.6	-	-	-
Oak-hickory	143.8	-	-	-	4.9	32.4	38.4	39.8	22.8	5.5
Elm-ash-soft maple	226.1	-	-	23.2	38.1	74.1	55.4	17.7	17.6	-
Maple-basswood	1,295.4	-	-	11.5	74.9	258.5	451.2	366.0	116.3	17.0
Aspen	1,017.5	-	-	9.3	57.9	177.0	302.4	340.2	118.2	12.5
Paper birch	196.3	-	-	-	12.8	45.5	79.2	51.1	7.7	-
Exotic	-	-	-	-	-	-	-	-	-	-
Nonstocked	20.1	-	2.0	1.8	5.4	5.6	1.9	3.4	-	-
All types	3,820.5	3.4	121.6	198.4	337.3	784.1	1,099.1	921.3	320.3	35.0
NORTHWEST										
Jack pine	242.6	-	-	1.9	35.8	74.5	103.5	20.6	4.5	1.8
Red pine	136.8	-	-	2.1	2.1	31.5	58.2	34.6	8.3	-
White pine	34.6	-	-	-	3.3	19.7	8.5	-	3.1	-
Balsam fir	212.0	3.2	1.7	18.0	57.9	60.3	51.8	10.8	6.5	1.8
White spruce	31.9	-	-	-	1.7	3.8	10.7	15.7	-	-
Black spruce	112.8	-	34.6	47.6	21.9	3.9	4.8	-	-	-
Northern white-cedar	110.6	3.5	34.0	14.0	37.1	8.9	13.1	-	-	-
Tamarack	111.5	-	12.9	23.7	30.6	14.5	24.5	3.6	1.7	-
Oak-hickory	410.9	-	-	12.4	41.4	135.1	114.1	90.7	17.2	-
Elm-ash-soft maple	412.1	-	1.8	33.0	98.6	136.0	77.9	43.4	21.4	-
Maple-basswood	1,487.7	-	-	12.6	88.9	348.4	531.5	359.8	130.2	16.3
Aspen	1,498.9	-	-	4.3	54.0	188.8	435.1	545.9	246.0	24.8
Paper birch	271.5	-	-	5.7	20.6	70.2	92.1	52.8	28.1	2.0
Exotic	-	-	-	-	-	-	-	-	-	-
Nonstocked	65.6	-	1.8	5.6	14.5	18.5	14.4	8.9	1.9	-
All types	5,139.5	6.7	86.8	180.9	508.4	1,114.1	1,540.2	1,186.8	468.9	46.7

(Table 4 continued on next page)

(Table 4 continued)

Forest type	All classes	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
		Site-index class (feet)								
CENTRAL										
Jack pine	198.0	-	-	4.7	23.7	61.4	71.3	34.6	2.3	-
Red pine	141.6	-	-	7.4	2.5	20.2	37.6	48.1	21.1	4.7
White pine	78.7	-	-	2.3	11.7	16.5	27.5	13.8	6.9	-
Balsam fir	11.9	-	-	-	7.1	2.4	2.4	-	-	-
White spruce	2.2	-	-	-	2.2	-	-	-	-	-
Black spruce	11.6	-	-	2.4	4.6	4.6	-	-	-	-
Northern white-cedar	25.3	-	7.3	10.3	5.1	-	2.6	-	-	-
Tamarack	38.2	-	-	4.4	11.0	11.5	6.7	2.3	2.3	-
Oak-hickory	935.9	-	-	54.5	131.8	276.6	267.1	123.6	71.1	11.2
Elm-ash-soft maple	269.8	-	-	2.2	23.0	78.1	94.0	47.0	25.5	-
Maple-basswood	509.6	-	-	4.9	26.8	118.9	177.1	107.4	60.5	14.0
Aspen	569.1	-	-	-	35.0	121.4	185.5	144.6	59.9	22.7
Paper birch	120.5	-	-	2.3	13.9	25.7	28.9	26.2	21.1	2.4
Exotic	2.2	-	-	-	-	-	-	2.2	-	-
Nonstocked	32.8	-	-	4.5	2.3	11.9	9.2	4.9	-	-
All types	2,947.4	-	7.3	99.9	300.7	749.2	909.9	554.7	270.7	55.0
SOUTHWEST										
Jack pine	10.2	-	-	-	2.5	7.7	-	-	-	-
Red pine	43.1	-	-	-	-	-	15.0	14.3	13.8	-
White pine	15.8	-	-	-	-	3.1	6.5	3.1	-	3.1
Balsam fir	-	-	-	-	-	-	-	-	-	-
White spruce	2.5	-	-	-	2.5	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	-	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-	-
Oak-hickory	1,061.5	-	-	35.6	148.4	271.6	257.2	217.2	89.8	41.7
Elm-ash-soft maple	115.5	-	-	5.2	5.5	24.4	36.5	22.3	12.9	8.7
Maple-basswood	495.6	-	-	8.9	51.2	112.9	103.6	116.0	80.7	22.3
Aspen	82.7	-	-	2.6	11.1	2.7	7.9	31.9	18.8	7.7
Paper birch	53.7	-	-	-	-	13.7	10.3	13.3	10.4	6.0
Exotic	-	-	-	-	-	-	-	-	-	-
Nonstocked	33.3	-	-	5.5	2.5	5.5	5.7	8.6	2.8	2.7
All types	1,913.9	-	-	57.8	223.7	441.6	442.7	426.7	229.2	92.2
SOUTHEAST										
Jack pine	2.7	-	-	-	-	2.7	-	-	-	-
Red pine	14.2	-	-	-	-	-	2.2	12.0	-	-
White pine	18.3	-	-	2.7	-	3.2	2.5	7.2	2.7	-
Balsam fir	-	-	-	-	-	-	-	-	-	-
White spruce	5.0	-	-	2.8	-	-	-	2.2	-	-
Black spruce	2.7	-	-	-	2.7	-	-	-	-	-
Northern white-cedar	54.7	-	10.7	16.6	8.0	11.6	5.1	2.7	-	-
Tamarack	9.2	-	-	-	-	-	9.2	-	-	-
Oak-hickory	295.5	-	-	24.6	65.4	76.2	65.4	38.7	20.2	5.0
Elm-ash-soft maple	200.5	-	5.4	11.1	24.4	34.4	35.9	54.1	22.9	12.3
Maple-basswood	229.0	-	-	2.4	12.0	55.4	59.8	51.4	30.6	17.4
Aspen	58.1	-	-	2.5	3.0	7.3	15.1	23.2	4.7	2.3
Paper birch	6.5	-	-	-	1.9	-	4.6	-	-	-
Exotic	-	-	-	-	-	-	-	-	-	-
Nonstocked	8.6	-	-	-	3.3	5.3	-	-	-	-
All types	905.0	-	16.1	62.7	120.7	196.1	199.8	191.5	81.1	37.0

Table 5.--Area of timberland by forest type, stand-size class, and Forest Survey Unit, Wisconsin, 1987

(In thousand acres)

Forest type	All classes	Sawtimber	Poletimber	Sapling and seedling	Nonstocked
		Stand size class			
ALL UNITS					
Jack pine	529.8	71.0	270.6	188.2	-
Red pine	500.4	156.7	200.5	143.2	-
White pine	230.3	155.4	45.1	29.8	-
Balsam fir	401.4	112.8	176.7	111.9	-
White spruce	61.4	23.0	20.2	18.2	-
Black spruce	277.3	5.5	82.7	189.1	-
Northern white-cedar	380.4	118.2	212.5	49.7	-
Tamarack	219.0	15.2	87.5	116.3	-
Oak-hickory	2,847.6	1,353.8	834.5	659.3	-
Elm-ash-soft maple	1,224.0	405.6	515.0	303.4	-
Maple-basswood	4,017.3	1,549.4	1,760.0	707.9	-
Aspen	3,226.3	350.6	1,510.9	1,364.8	-
Paper birch	648.5	80.1	420.9	147.5	-
Exotic	2.2	-	-	2.2	-
Nonstocked	160.4	-	-	-	160.4
All types	14,726.3	4,397.3	6,137.1	4,031.5	160.4
NORTHEAST					
Jack pine	76.3	20.3	34.3	21.7	-
Red pine	164.7	79.5	58.6	26.6	-
White pine	82.9	59.9	15.9	7.1	-
Balsam fir	177.5	33.1	87.2	57.2	-
White spruce	19.8	9.3	5.5	5.0	-
Black spruce	150.2	3.7	54.6	91.9	-
Northern white-cedar	189.8	45.7	116.4	27.7	-
Tamarack	60.1	1.6	26.3	32.2	-
Oak-hickory	143.8	56.9	57.3	29.6	-
Elm-ash-soft maple	226.1	66.8	108.6	50.7	-
Maple-basswood	1,295.4	516.4	633.6	145.4	-
Aspen	1,017.5	110.0	451.6	455.9	-
Paper birch	196.3	22.9	142.0	31.4	-
Exotic	-	-	-	-	-
Nonstocked	20.1	-	-	-	20.1
All types	3,820.5	1,026.1	1,791.9	982.4	20.1
NORTHWEST					
Jack pine	242.6	30.4	139.2	73.0	-
Red pine	136.8	53.3	29.4	54.1	-
White pine	34.6	29.6	5.0	-	-
Balsam fir	212.0	77.4	89.5	45.1	-
White spruce	31.9	13.7	12.5	5.7	-
Black spruce	112.8	1.8	28.1	82.9	-
Northern white-cedar	110.6	45.7	56.9	8.0	-
Tamarack	111.5	9.3	40.5	61.7	-
Oak-hickory	410.9	107.4	176.2	127.3	-
Elm-ash-soft maple	412.1	104.7	211.2	96.2	-
Maple-basswood	1,487.7	454.0	821.1	212.6	-
Aspen	1,498.9	152.8	744.0	602.1	-
Paper birch	271.5	26.9	196.5	48.1	-
Exotic	-	-	-	-	-
Nonstocked	65.6	-	-	-	65.6
All types	5,139.5	1,107.0	2,550.1	1,416.8	65.6

(Table 5 continued on next page)

(Table 5 continued)

Forest type	All classes	Stand size class			
		Sawtimber	Poletimber	Sapling and seedling	Nonstocked
		CENTRAL			
Jack pine	198.0	15.1	94.4	88.5	-
Red pine	141.6	18.4	79.0	44.2	-
White pine	78.7	60.4	11.5	6.8	-
Balsam fir	11.9	2.3	-	9.6	-
White spruce	2.2	-	-	2.2	-
Black spruce	11.6	-	-	11.6	-
Northern white-cedar	25.3	2.4	20.5	2.4	-
Tamarack	38.2	2.2	16.1	19.9	-
Oak-hickory	935.9	311.5	381.9	242.5	-
Elm-ash-soft maple	269.8	93.4	94.9	81.5	-
Maple-basswood	509.6	226.1	131.7	151.8	-
Aspen	569.1	56.7	255.7	256.7	-
Paper birch	120.5	11.8	52.7	56.0	-
Exotic	2.2	-	-	2.2	-
Nonstocked	32.8	-	-	-	32.8
All types	2,947.4	800.3	1,138.4	975.9	32.8
		SOUTHWEST			
Jack pine	10.2	5.2	-	5.0	-
Red pine	43.1	3.3	27.5	12.3	-
White pine	15.8	-	3.1	12.7	-
Balsam fir	-	-	-	-	-
White spruce	2.5	-	-	2.5	-
Black spruce	-	-	-	-	-
Northern white-cedar	-	-	-	-	-
Tamarack	-	-	-	-	-
Oak-hickory	1,061.5	658.6	187.2	215.7	-
Elm-ash-soft maple	115.5	63.5	17.2	34.8	-
Maple-basswood	495.6	222.4	118.1	155.1	-
Aspen	82.7	21.3	37.8	23.6	-
Paper birch	53.7	18.5	27.1	8.1	-
Exotic	-	-	-	-	-
Nonstocked	33.3	-	-	-	33.3
All types	1,913.9	992.8	418.0	469.8	33.3
		SOUTHEAST			
Jack pine	2.7	-	2.7	-	-
Red pine	14.2	2.2	6.0	6.0	-
White pine	18.3	5.5	9.6	3.2	-
Balsam fir	-	-	-	-	-
White spruce	5.0	-	2.2	2.8	-
Black spruce	2.7	-	-	2.7	-
Northern white-cedar	54.7	24.4	18.7	11.6	-
Tamarack	9.2	2.1	4.6	2.5	-
Oak-hickory	295.5	219.4	31.9	44.2	-
Elm-ash-soft maple	200.5	77.2	83.1	40.2	-
Maple-basswood	229.0	130.5	55.5	43.0	-
Aspen	58.1	9.8	21.8	26.5	-
Paper birch	6.5	-	2.6	3.9	-
Exotic	-	-	-	-	-
Nonstocked	8.6	-	-	-	8.6
All types	905.0	471.1	238.7	186.6	8.6

Table 6.--Net volume of growing stock on timberland by forest type, stand-age class, and Forest Survey Unit, Wisconsin, 1987

(In thousand cubic feet)

		Stand-age class(years)									
Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
					ALL UNITS						
Jack pine	476,867	52,308	53,059	133,161	178,350	53,571	3,468	2,303	647	-	-
Red pine	913,459	148,176	256,712	233,813	133,915	53,194	13,651	19,717	45,164	9,117	-
White pine	386,116	23,068	14,636	21,423	43,773	33,261	49,537	70,936	62,747	20,802	45,933
Balsam fir	428,018	40,070	30,786	46,285	69,777	133,251	57,520	15,939	19,674	7,556	7,160
White spruce	123,741	11,143	25,458	44,020	12,751	23,631	6,738	-	-	-	-
Black spruce	133,866	17,873	21,025	11,553	17,556	10,086	11,393	31,109	13,271	-	-
Northern white-cedar	511,648	14,382	10,635	8,111	59,332	52,206	61,150	43,907	145,539	45,808	70,578
Tamarack	128,268	20,143	13,186	9,674	22,072	13,497	19,249	14,862	10,750	3,330	1,505
Oak-hickory	2,922,708	154,582	64,598	120,766	419,094	618,307	334,490	384,139	536,147	191,256	99,329
Elm-ash-soft maple	1,207,267	96,993	69,553	123,551	184,435	142,713	165,411	174,615	172,722	45,370	31,904
Maple-basswood	5,515,107	272,459	191,032	340,838	945,905	1,094,978	830,637	387,151	704,427	328,208	419,472
Aspen	2,901,603	408,518	250,603	589,629	1,054,408	419,986	99,353	48,664	30,442	-	-
Paper birch	829,867	53,121	54,416	128,007	219,888	213,712	135,260	22,975	858	1,630	-
Exotic	1,011	1,011	-	-	-	-	-	-	-	-	-
Nonstocked	18,692	18,692	-	-	-	-	-	-	-	-	-
All types	16,498,238	1,332,539	1,055,699	1,810,831	3,361,256	2,862,393	1,787,857	1,216,317	1,742,388	653,077	675,881
					NORTHEAST						
Jack pine	69,781	3,774	8,451	28,735	10,882	16,503	1,436	-	-	-	-
Red pine	328,568	34,371	63,597	115,111	60,253	4,360	11,993	7,346	22,420	9,117	-
White pine	156,973	7,258	10,411	8,541	9,174	18,482	496	30,140	31,600	6,810	34,061
Balsam fir	192,347	18,701	9,015	26,107	30,490	63,677	15,678	12,890	7,039	4,251	4,499
White spruce	35,552	8,431	-	-	3,490	23,631	-	-	-	-	-
Black spruce	87,270	9,032	14,350	3,121	8,361	6,796	10,280	25,989	9,341	-	-
Northern white-cedar	273,317	7,309	7,807	3,121	24,105	22,261	33,905	22,365	84,636	28,442	39,366
Tamarack	36,022	3,234	7,381	718	-	4,237	13,428	3,350	2,683	991	-
Oak-hickory	188,920	12,405	2,666	4,266	25,987	56,934	22,994	33,685	18,058	10,085	1,840
Elm-ash-soft maple	234,405	16,397	11,653	25,624	31,905	22,873	53,162	28,205	30,886	3,452	10,248
Maple-basswood	1,962,500	57,633	47,576	102,403	371,692	355,567	279,241	118,211	206,931	151,503	271,743
Aspen	870,164	155,411	68,434	165,139	302,569	121,966	35,651	12,968	8,026	-	-
Paper birch	296,748	12,371	21,306	20,813	74,152	86,267	66,046	14,935	858	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	884	884	-	-	-	-	-	-	-	-	-
All types	4,733,451	347,211	272,647	503,699	953,060	803,554	544,310	310,084	422,478	214,651	361,757
					NORTHWEST						
Jack pine	248,454	21,330	25,199	59,987	110,797	26,961	2,032	1,501	647	-	-
Red pine	228,255	21,433	23,498	54,791	65,598	32,396	1,658	12,371	16,510	-	-
White pine	78,131	-	-	-	6,862	7,525	25,529	29,371	6,383	2,461	-
Balsam fir	227,254	12,574	21,433	20,178	37,671	69,574	41,842	3,049	12,635	3,305	2,661
White spruce	85,025	2,096	25,458	41,472	9,261	-	6,738	-	-	-	-
Black spruce	42,085	5,926	6,675	8,432	7,599	3,290	1,113	5,120	3,930	-	-
Northern white-cedar	120,875	130	2,828	33	23,870	4,617	17,522	10,088	31,949	5,457	24,381
Tamarack	63,994	12,157	5,805	5,046	16,690	5,806	490	8,124	6,032	2,339	1,505
Oak-hickory	429,217	29,370	5,692	18,647	65,798	175,739	44,336	45,342	36,550	7,743	-
Elm-ash-soft maple	394,128	20,994	26,479	40,824	61,757	59,816	57,422	43,438	49,798	17,180	16,420
Maple-basswood	2,170,374	90,164	70,896	124,389	458,631	540,048	375,661	161,759	199,257	72,815	76,754
Aspen	1,373,729	165,189	113,348	288,035	523,114	220,601	44,889	12,786	5,767	-	-
Paper birch	351,290	21,209	21,691	51,883	119,713	80,320	49,103	5,741	-	1,630	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	7,521	7,521	-	-	-	-	-	-	-	-	-
All types	5,820,332	412,425	349,002	713,717	1,507,361	1,226,693	668,335	338,690	369,458	112,930	121,721

(Table 6 continued on next page)

(Table 6 continued)

Forest type	All ages	Stand-age class(years)									
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
CENTRAL											
Jack pine	149,095	27,204	19,409	38,151	53,422	10,107	-	802	-	-	-
Red pine	251,702	54,431	124,819	41,716	8,064	16,438	-	-	6,234	-	-
White pine	125,723	8,620	-	12,882	16,252	7,254	23,512	11,425	22,375	11,531	11,872
Balsam fir	8,417	6,463	338	-	1,616	-	-	-	-	-	-
White spruce	616	616	-	-	-	-	-	-	-	-	-
Black spruce	3,341	1,745	-	-	1,596	-	-	-	-	-	-
Northern white-cedar	37,293	-	-	-	-	17,267	5,363	7,304	7,359	-	-
Tamarack	22,337	4,300	-	1,761	3,369	3,454	4,030	3,388	2,035	-	-
Oak-hickory	877,057	51,737	20,990	49,373	156,582	219,000	137,582	143,964	91,791	6,038	-
Elm-ash-soft maple	273,526	29,872	350	24,924	50,521	28,904	23,018	56,304	48,865	8,486	2,282
Maple-basswood	609,503	54,962	23,335	39,318	62,256	91,121	101,446	57,061	124,052	27,908	28,044
Aspen	516,691	65,360	45,899	109,686	204,310	52,926	5,566	19,042	13,902	-	-
Paper birch	106,752	15,200	8,911	36,779	9,201	19,774	14,588	2,299	-	-	-
Exotic	1,011	1,011	-	-	-	-	-	-	-	-	-
Nonstocked	5,280	5,280	-	-	-	-	-	-	-	-	-
All types	2,988,344	326,801	244,051	354,590	567,189	466,245	315,105	301,589	316,613	53,963	42,198
SOUTHWEST											
Jack pine	5,960	-	-	2,711	3,249	-	-	-	-	-	-
Red pine	80,936	21,941	44,798	14,197	-	-	-	-	-	-	-
White pine	4,155	4,155	-	-	-	-	-	-	-	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	-	-	-	-	-	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	-	-	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-	-	-
Oak-hickory	1,130,327	56,884	29,923	39,207	155,774	135,485	113,452	122,330	305,162	132,767	39,343
Elm-ash-soft maple	124,219	13,046	5,600	8,391	14,609	15,127	9,454	19,543	26,203	12,246	-
Maple-basswood	481,974	46,420	29,542	54,991	41,785	62,000	24,481	16,461	118,209	60,419	27,666
Aspen	91,718	12,070	14,800	12,225	18,812	19,717	11,347	-	2,747	-	-
Paper birch	70,081	4,027	2,508	13,850	16,822	27,351	5,523	-	-	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	4,267	4,267	-	-	-	-	-	-	-	-	-
All types	1,993,637	162,810	127,171	145,572	251,051	259,680	164,257	158,334	452,321	205,432	67,009
SOUTHEAST											
Jack pine	3,577	-	-	3,577	-	-	-	-	-	-	-
Red pine	23,998	16,000	-	7,998	-	-	-	-	-	-	-
White pine	21,134	3,035	4,225	-	11,485	-	-	-	2,389	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	2,548	-	-	2,548	-	-	-	-	-	-	-
Black spruce	1,170	1,170	-	-	-	-	-	-	-	-	-
Northern white-cedar	80,163	6,943	-	4,957	11,357	8,061	4,360	4,150	21,595	11,909	6,831
Tamarack	5,915	452	-	2,149	2,013	-	1,301	-	-	-	-
Oak-hickory	297,187	4,186	5,327	9,273	14,953	31,149	16,126	38,818	84,586	34,623	58,146
Elm-ash-soft maple	180,989	16,684	25,471	23,788	25,643	15,993	22,355	27,125	16,970	4,006	2,954
Maple-basswood	290,756	23,280	19,683	19,737	11,541	46,242	49,808	33,659	55,978	15,563	15,265
Aspen	49,301	10,488	8,122	14,544	5,603	4,776	1,900	3,868	-	-	-
Paper birch	4,996	314	-	4,682	-	-	-	-	-	-	-
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	740	740	-	-	-	-	-	-	-	-	-
All types	962,474	83,292	62,828	93,253	82,595	106,221	95,850	107,620	181,518	66,101	83,196

Table 7.--Net volume of sawtimber on timberland by forest type, stand-age class, and Forest Survey Unit, Wisconsin, 1987

(In thousand board feet) 1/

ALL UNITS

		Stand-age class(years)									
Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	894,081	58,288	48,131	216,210	387,378	155,832	15,176	11,139	1,927	-	-
Red pine	2,183,757	106,254	268,187	664,853	502,388	224,864	65,335	95,154	213,866	42,856	-
White pine	1,564,709	36,144	39,362	63,558	151,678	118,675	205,226	322,863	285,175	95,116	246,912
Balsam fir	980,204	74,326	57,328	89,285	146,949	342,139	130,502	32,524	58,393	24,561	24,197
White spruce	349,796	19,849	71,371	133,399	31,543	60,227	33,407	-	-	-	-
Black spruce	186,487	19,723	25,589	9,905	8,953	8,859	11,597	76,130	25,731	-	-
Northern white-cedar	1,000,013	15,072	17,862	11,277	106,811	85,440	75,636	71,057	253,679	128,314	234,865
Tamarack	173,826	31,922	9,652	3,390	33,318	9,992	30,624	26,957	18,699	4,988	4,284
Oak-hickory	8,642,347	389,453	130,793	205,959	806,959	1,449,407	971,491	1,325,524	2,124,532	802,690	435,539
Elm-ash-soft maple	2,952,890	186,781	93,284	208,393	381,075	306,902	399,289	531,243	580,622	146,742	118,559
Maple-basswood	14,504,660	564,524	355,670	578,487	1,624,961	2,358,534	2,116,537	1,220,760	2,649,116	1,252,663	1,783,408
Aspen	4,599,970	605,867	325,430	857,660	1,532,541	843,321	210,463	134,947	89,741	-	-
Paper birch	1,381,801	71,991	62,092	178,341	314,087	396,515	295,094	56,245	2,190	5,246	-
Nonstocked	36,323	36,323	-	-	-	-	-	-	-	-	-
All types	39,450,864	2,216,517	1,504,751	3,220,717	6,028,641	6,360,707	4,560,377	3,904,543	6,303,671	2,503,176	2,847,764
NORTHEAST											
Jack pine	152,830	5,061	5,681	58,254	31,127	45,630	7,077	-	-	-	-
Red pine	942,141	41,727	79,865	355,253	204,545	15,709	56,740	37,035	108,411	42,856	-
White pine	684,857	32,235	32,377	25,244	29,997	67,702	2,704	137,823	143,666	26,040	187,069
Balsam fir	396,358	27,642	13,296	48,347	66,979	142,462	24,986	23,094	19,457	14,432	15,663
White spruce	90,142	17,543	-	-	12,372	60,227	-	-	-	-	-
Black spruce	133,212	11,355	15,699	927	6,710	6,812	11,045	64,626	16,038	-	-
Northern white-cedar	457,121	11,460	14,103	5,762	32,233	39,428	27,827	29,862	104,907	61,818	129,721
Tamarack	41,962	5,305	4,679	668	-	5,198	23,453	542	582	1,535	-
Oak-hickory	481,755	33,075	6,759	11,109	38,605	97,646	59,508	126,786	60,619	37,016	10,632
Elm-ash-soft maple	530,636	29,783	13,408	40,037	59,384	48,407	120,186	66,470	99,978	12,353	40,630
Maple-basswood	5,179,088	99,109	70,330	161,250	594,732	685,698	669,743	384,199	780,358	588,678	1,144,991
Aspen	1,408,354	208,252	98,272	279,990	449,742	244,442	70,951	35,462	21,243	-	-
Paper birch	503,721	15,011	32,829	33,908	104,948	150,543	124,549	39,743	2,190	-	-
Nonstocked	2,155	2,155	-	-	-	-	-	-	-	-	-
All types	11,004,332	539,713	387,298	1,020,749	1,631,374	1,609,904	1,198,769	945,642	1,357,449	784,728	1,528,706
NORTHWEST											
Jack pine	426,022	22,439	24,245	66,246	219,029	77,531	8,099	6,506	1,927	-	-
Red pine	712,381	21,152	15,133	143,543	261,353	133,634	8,595	58,119	70,852	-	-
White pine	329,995	-	-	-	17,131	24,722	102,638	139,924	31,739	13,841	-
Balsam fir	564,509	31,860	43,064	40,938	76,425	199,677	105,516	9,430	38,936	10,129	8,534
White spruce	256,685	2,306	71,371	130,430	19,171	-	33,407	-	-	-	-
Black spruce	51,968	7,061	9,890	8,978	2,243	2,047	552	11,504	9,693	-	-
Northern white-cedar	315,019	586	3,759	-	48,044	9,488	38,370	22,240	88,162	23,289	81,081
Tamarack	101,225	18,930	4,973	2,722	28,307	3,111	-	20,651	14,794	3,453	4,284
Oak-hickory	911,229	65,355	3,531	32,616	76,997	335,484	91,978	132,227	141,440	31,601	-
Elm-ash-soft maple	804,413	35,425	20,976	64,499	103,825	110,608	138,047	108,045	128,597	40,098	54,293
Maple-basswood	4,969,979	150,121	96,525	177,768	786,006	1,151,314	885,825	455,002	688,946	262,336	316,136
Aspen	2,172,061	292,523	129,657	389,987	778,079	440,142	79,724	41,794	20,155	-	-
Paper birch	493,873	23,829	18,604	56,866	146,600	129,940	102,537	10,251	-	5,246	-
Nonstocked	9,917	9,917	-	-	-	-	-	-	-	-	-
All types	12,119,276	681,504	441,728	1,114,593	2,563,210	2,617,698	1,595,288	1,015,693	1,235,241	389,993	464,328

(Table 7 continued on next page)

(Table 7 continued)

CENTRAL

Forest type	All ages	Stand-age class(years) 1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	288,206	30,788	18,205	79,184	122,725	32,671	-	4,633	-	-	-
Red pine	376,564	34,761	119,243	75,946	36,490	75,521	-	-	34,603	-	-
White pine	482,421	3,322	-	38,314	57,476	26,251	99,884	45,116	96,980	55,235	59,843
Balsam fir	19,337	14,828	968	-	3,545	-	-	-	-	-	-
White spruce	-	-	-	-	-	-	-	-	-	-	-
Black spruce	1,307	1,307	-	-	-	-	-	-	-	-	-
Northern white-cedar	54,678	-	-	-	-	16,738	7,200	16,015	14,725	-	-
Tamarack	22,691	6,761	-	-	2,163	1,683	2,997	5,764	3,323	-	-
Oak-hickory	2,279,325	117,289	46,061	89,929	269,579	487,423	399,859	487,034	363,731	18,420	-
Elm-ash-soft maple	682,432	44,686	-	46,870	81,514	57,145	43,786	188,586	171,323	37,504	11,018
Maple-basswood	1,806,907	113,971	59,685	82,651	129,687	208,082	295,919	204,359	479,118	108,194	125,241
Aspen	708,366	72,363	52,520	152,179	262,655	64,434	18,464	50,001	35,750	-	-
Paper birch	195,211	21,154	5,167	54,993	15,529	38,419	53,698	6,251	-	-	-
Nonstocked	9,558	9,558	-	-	-	-	-	-	-	-	-
All types	6,927,003	470,784	301,849	620,066	981,363	1,008,367	921,807	1,007,759	1,199,553	219,353	196,102

SOUTHWEST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	27,023	-	-	12,526	14,497	-	-	-	-	-	-
Red pine	115,767	2,866	53,946	58,955	-	-	-	-	-	-	-
White pine	-	-	-	-	-	-	-	-	-	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	-	-	-	-	-	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	-	-	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-	-	-
Oak-hickory	3,832,873	161,811	64,673	58,812	384,329	426,160	356,579	434,629	1,220,295	563,156	162,429
Elm-ash-soft maple	422,897	38,064	10,232	17,851	53,205	45,935	34,446	82,386	100,644	40,134	-
Maple-basswood	1,579,917	135,995	82,252	119,676	85,094	180,386	85,667	53,018	481,152	228,877	127,800
Aspen	217,497	16,958	33,433	23,053	23,347	73,746	34,367	-	12,593	-	-
Paper birch	179,096	11,997	5,492	22,674	47,010	77,613	14,310	-	-	-	-
Nonstocked	12,581	12,581	-	-	-	-	-	-	-	-	-
All types	6,387,651	380,272	250,028	313,547	607,482	803,840	525,369	570,033	1,814,684	832,167	290,229

SOUTHEAST

Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Jack pine	-	-	-	-	-	-	-	-	-	-	-
Red pine	36,904	5,748	-	31,156	-	-	-	-	-	-	-
White pine	67,436	587	6,985	-	47,074	-	-	-	12,790	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	2,969	-	-	2,969	-	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	173,195	3,026	-	5,515	26,534	19,786	2,239	2,940	45,885	43,207	24,063
Tamarack	7,948	926	-	-	2,848	-	4,174	-	-	-	-
Oak-hickory	1,137,165	11,923	9,769	13,493	37,449	102,694	63,567	144,848	338,447	152,497	262,478
Elm-ash-soft maple	512,512	38,823	48,668	39,136	83,147	44,807	62,824	85,756	80,080	16,653	12,618
Maple-basswood	968,769	65,328	46,878	37,142	29,442	133,054	179,383	124,182	219,542	64,578	69,240
Aspen	93,692	15,771	11,548	12,451	18,718	20,557	6,957	7,690	-	-	-
Paper birch	9,900	-	-	9,900	-	-	-	-	-	-	-
Nonstocked	2,112	2,112	-	-	-	-	-	-	-	-	-
All types	3,012,602	144,244	123,848	151,762	245,212	320,898	319,144	365,416	696,744	276,935	368,399

1/ International 1/4-inch rule

Table 8.--Growing-stock volume and periodic growth on timberland by forest type, component of growth, and Forest Survey Unit, Wisconsin, 1983-1987

(In thousand cubic feet)

	1/	Components							
Forest type	1983 growing stock volume	Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	1987 growing stock volume
ALL UNITS									
Jack pine	446,132	64,460	32,777	11,432	-17,640	91,029	-46,545	-13,749	476,867
Red pine	735,172	142,870	51,973	25,436	-7,951	212,328	-32,901	-1,140	913,459
White pine	356,675	49,926	4,579	10,010	-3,956	60,559	-28,339	-2,779	386,116
Balsam fir	397,258	70,033	13,454	7,171	-14,789	75,869	-28,241	-16,868	428,018
White spruce	97,257	26,010	3,112	1,226	-2,275	28,073	-1,589	-	123,741
Black spruce	119,378	15,064	7,217	3,036	-9,928	15,389	-901	-	133,866
Northern white-cedar	468,162	40,806	19,600	14,342	-14,646	60,102	-16,616	-	511,648
Tamarack	116,405	15,455	4,335	642	-5,150	15,282	-1,677	-1,742	128,268
Oak-hickory	3,012,870	274,481	42,188	43,661	-81,225	279,105	-354,860	-14,407	2,922,708
Elm-ash-soft maple	1,154,619	132,053	34,926	15,466	-31,922	150,523	-78,293	-19,582	1,207,267
Maple-basswood	4,984,022	669,448	101,425	86,565	-132,182	725,256	-186,149	-8,022	5,515,107
Aspen	2,826,339	454,179	123,891	99,810	-112,615	565,265	-457,245	-32,756	2,901,603
Paper birch	716,255	102,767	26,986	14,453	-17,517	126,689	-10,822	-2,255	829,867
Exotic	529	134	290	58	-	482	-	-	1,011
Nonstocked	17,274	2,683	-	128	-121	2,690	-1,272	-	18,692
All types	15,448,347	2,060,369	466,753	333,436	-451,917	2,408,641	-1,245,450	-113,300	16,498,238
NORTHEAST									
Jack pine	75,124	9,338	3,773	2,381	-3,290	12,202	-12,441	-5,104	69,781
Red pine	262,262	51,441	14,954	6,296	-3,773	68,918	-1,472	-1,140	328,568
White pine	152,842	19,158	2,113	4,868	-2,714	23,425	-19,294	-	156,973
Balsam fir	184,727	28,410	6,420	2,618	-5,697	31,751	-14,229	-9,902	192,347
White spruce	26,704	7,864	1,594	347	-475	9,330	-482	-	35,552
Black spruce	79,271	9,324	3,523	2,165	-6,276	8,736	-737	-	87,270
Northern white-cedar	252,458	21,366	12,473	6,381	-8,852	31,368	-10,509	-	273,317
Tamarack	32,550	3,609	2,282	129	-924	5,096	-270	-1,354	36,022
Oak-hickory	201,222	21,164	1,916	4,211	-7,858	19,433	-25,284	-6,451	188,920
Elm-ash-soft maple	234,000	27,886	8,998	4,248	-7,169	33,963	-24,147	-9,411	234,405
Maple-basswood	1,822,033	233,871	28,126	42,813	-48,438	256,372	-115,905	-	1,962,500
Aspen	893,697	133,633	39,151	41,447	-34,653	179,578	-192,924	-10,187	870,164
Paper birch	256,419	35,357	7,884	6,871	-6,602	43,510	-3,181	-	296,748
Exotic	-	-	-	-	-	-	-	-	-
Nonstocked	732	152	-	-	-	152	-	-	884
All types	4,474,041	602,573	133,207	124,775	-136,721	723,834	-420,875	-43,549	4,733,451
NORTHWEST									
Jack pine	215,576	37,914	18,293	5,757	-8,849	53,115	-16,108	-4,129	248,454
Red pine	173,884	40,404	16,015	3,482	-2,266	57,635	-3,264	-	228,255
White pine	70,904	11,674	645	309	-716	11,912	-1,906	-2,779	78,131
Balsam fir	205,362	40,427	6,762	4,468	-8,787	42,870	-14,012	-6,966	227,254
White spruce	67,843	17,747	1,255	766	-1,800	17,968	-786	-	85,025
Black spruce	36,652	5,196	3,018	826	-3,443	5,597	-164	-	42,085
Northern white-cedar	111,579	12,176	3,336	3,250	-3,653	15,109	-5,813	-	120,875
Tamarack	57,196	8,991	2,053	446	-3,754	7,736	-938	-	63,994
Oak-hickory	413,258	56,673	13,435	8,848	-16,264	62,692	-42,033	-4,700	429,217
Elm-ash-soft maple	384,331	49,394	12,268	7,166	-16,426	52,402	-35,840	-6,765	394,128
Maple-basswood	1,898,617	295,546	52,896	29,049	-54,571	322,920	-51,163	-	2,170,374
Aspen	1,305,016	238,890	62,004	49,056	-60,761	289,189	-212,208	-8,268	1,373,729
Paper birch	299,165	47,611	16,150	5,781	-9,776	59,766	-7,641	-	351,290
Exotic	-	-	-	-	-	-	-	-	-
Nonstocked	6,125	1,506	-	23	-	1,529	-133	-	7,521
All types	5,245,508	864,149	208,130	119,227	-191,066	1,000,440	-392,009	-33,607	5,820,332

(Table 8 continued on next page)

(Table 8 continued)

Forest type	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
				CENTRAL					
Jack pine	142,641	16,395	9,958	2,161	-4,770	23,744	-13,555	-3,735	149,095
Red pine	217,333	36,195	14,145	9,763	-1,115	58,988	-24,619	-	251,702
White pine	112,743	14,123	965	1,733	-526	16,295	-3,315	-	125,723
Balsam fir	7,169	1,196	272	85	-305	1,248	-	-	8,417
White spruce	146	129	263	78	-	470	-	-	616
Black spruce	2,475	354	676	45	-209	866	-	-	3,341
Northern white-cedar	32,533	2,468	878	2,919	-1,211	5,054	-294	-	37,293
Tamarack	20,697	2,294	-	29	-150	2,173	-145	-388	22,337
Oak-hickory	913,469	84,219	10,149	11,821	-26,100	80,089	-115,185	-1,316	877,057
Elm-ash-soft maple	250,648	27,530	10,377	1,671	-4,505	35,073	-10,839	-1,356	273,526
Maple-basswood	555,058	64,996	6,496	6,460	-9,885	68,067	-13,622	-	609,503
Aspen	495,008	64,971	20,284	8,715	-13,251	80,719	-51,594	-7,442	516,691
Paper birch	91,415	12,637	1,529	1,712	-541	15,337	-	-	106,752
Exotic	529	134	290	58	-	482	-	-	1,011
Nonstocked	5,212	593	-	16	-121	488	-420	-	5,280
All types	2,847,076	328,234	76,282	47,266	-62,689	389,093	-233,588	-14,237	2,988,344
				SOTHWEST					
Jack pine	10,461	457	-	995	-731	721	-4,441	-781	5,960
Red pine	66,863	11,011	3,542	2,957	-797	16,713	-2,640	-	80,936
White pine	5,174	948	474	1,383	-	2,805	-3,824	-	4,155
Balsam fir	-	-	-	-	-	-	-	-	-
White spruce	-	-	-	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-
Northern white-cedar	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-
Oak-hickory	1,173,608	91,638	12,797	11,484	-25,470	90,449	-131,790	-1,940	1,130,327
Elm-ash-soft maple	115,416	11,494	1,166	1,887	-1,685	12,862	-2,009	-2,050	124,219
Maple-basswood	438,298	45,406	7,786	1,352	-7,149	47,395	-1,696	-2,023	481,974
Aspen	85,904	11,026	-	209	-2,452	8,783	-	-2,969	91,718
Paper birch	63,487	6,708	1,423	89	-598	7,622	-	-1,028	70,081
Exotic	-	-	-	-	-	-	-	-	-
Nonstocked	4,577	320	-	89	-	409	-719	-	4,267
All types	1,963,788	179,008	27,188	20,445	-38,882	187,759	-147,119	-10,791	1,993,637
				SOTHEAST					
Jack pine	2,330	356	753	138	-	1,247	-	-	3,577
Red pine	14,830	3,819	3,317	2,938	-	10,074	-906	-	23,998
White pine	15,012	4,023	382	1,717	-	6,122	-	-	21,134
Balsam fir	-	-	-	-	-	-	-	-	-
White spruce	2,564	270	-	35	-	305	-321	-	2,548
Black spruce	980	190	-	-	-	190	-	-	1,170
Northern white-cedar	71,592	4,796	2,913	1,792	-930	8,571	-	-	80,163
Tamarack	5,962	561	-	38	-322	277	-324	-	5,915
Oak-hickory	311,313	20,787	3,891	7,297	-5,533	26,442	-40,568	-	297,187
Elm-ash-soft maple	170,224	15,749	2,117	494	-2,137	16,223	-5,458	-	180,989
Maple-basswood	270,016	29,629	6,121	6,891	-12,139	30,502	-3,763	-5,999	290,756
Aspen	46,714	5,659	2,452	383	-1,498	6,996	-519	-3,890	49,301
Paper birch	5,769	454	-	-	-	454	-	-1,227	4,996
Exotic	-	-	-	-	-	-	-	-	-
Nonstocked	628	112	-	-	-	112	-	-	740
All types	917,934	86,405	21,946	21,723	-22,559	107,515	-51,859	-11,116	962,474

1/ Figures have been adjusted from those published after the 1983 survey to conform to changes in survey definitions and procedures

2/ Includes growth on ingrowth, mortality and removals.

Table 9.--Growing-stock volume and periodic growth on timberland by species group, and component of growth, and Forest Survey Unit, Wisconsin, 1983-1987

(In thousand cubic feet)

ALL UNITS

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	533,134	71,812	24,593	15,390	-23,640	88,155	-63,821	-12,469	544,999
Red pine	773,252	145,907	59,022	33,965	-1,035	237,859	-80,929	-2,852	927,330
White pine	560,709	88,645	3,902	10,981	-4,372	99,156	-35,661	-3,464	620,740
White spruce	196,912	67,269	6,185	6,053	-2,106	77,401	-11,103	-1,591	261,619
Black spruce	119,539	13,401	5,907	2,684	-12,890	9,102	-4,327	-1,124	123,190
Balsam fir	546,635	118,523	20,451	14,537	-26,651	126,860	-27,774	-9,292	636,429
Hemlock	277,776	31,194	547	3,710	-2,553	32,898	-10,810	-608	299,256
Tamarack	136,648	12,613	5,132	1,630	-8,061	11,314	-1,269	-1,727	144,966
Eastern redcedar	3,354	659	372	56	-	1,087	-	-14	4,427
Northern white-cedar	472,514	44,192	17,662	8,288	-2,071	68,071	-7,653	-3,536	529,396
Other softwoods	3,673	999	290	204	-121	1,372	-	-42	5,003
Total	3,624,146	595,214	144,063	97,498	-83,500	753,275	-243,347	-36,719	4,097,355
Hardwoods									
Select white oak	634,266	46,121	2,596	4,017	-871	51,863	-43,647	-3,179	639,303
Select red oak	1,431,209	148,635	12,442	16,640	-42,564	135,153	-109,883	-8,019	1,448,460
Other red oak	627,280	52,443	1,893	4,560	-27,884	31,012	-47,298	-3,532	607,462
Select hickory	117,940	8,603	3,092	714	-2,136	10,273	-3,437	-395	124,381
Other hickory	75,618	6,782	3,244	1,247	-2,700	8,573	-875	-383	82,933
Basswood	825,011	121,402	6,569	12,308	-18,513	121,766	-29,652	-2,043	915,082
Beech	29,039	2,200	546	328	-724	2,350	-1,988	-320	29,081
Yellow birch	204,483	18,802	1,852	3,432	-10,151	13,935	-11,437	-395	206,586
Hard maple	1,481,166	201,385	43,495	32,313	-24,426	252,767	-88,766	-2,855	1,642,312
Soft maple	1,221,591	174,756	61,340	17,530	-24,289	229,337	-44,035	-8,768	1,398,125
Elm	428,274	49,005	3,831	12,762	-28,705	36,893	-80,764	-3,166	381,237
Black ash	417,941	37,406	25,724	5,664	-15,006	53,788	-14,152	-5,344	452,233
White & green ash	320,178	37,108	3,374	3,965	-5,054	39,393	-10,092	-2,607	346,872
Cottonwood	31,091	2,999	-	209	-460	2,748	-1,318	-424	32,097
Willow	24,150	2,858	-	49	-257	2,650	-	-384	26,416
Hackberry	2,134	343	-	25	-235	133	-	-26	2,241
Balsam poplar	38,513	6,480	500	598	-3,719	3,859	-1,303	-678	40,391
Bigtooth aspen	692,432	118,385	10,213	20,866	-32,769	116,695	-92,197	-5,822	711,108
Quaking aspen	1,929,216	284,458	32,428	79,207	-104,618	341,475	-354,314	-19,215	1,897,162
Paper birch	1,026,288	116,362	47,744	15,990	-19,293	160,803	-56,005	-7,072	1,124,014
River birch	9,690	1,555	-	1,257	-	2,812	-1,352	-142	11,008
Black cherry	168,293	18,533	9,521	1,875	-1,743	28,186	-4,553	-1,305	190,621
Black walnut	23,089	2,076	-	150	-400	1,826	-836	-19	24,060
Butternut	39,626	3,880	836	212	-	4,928	-776	-222	43,556
Other hardwoods	25,683	2,578	1,450	20	-1,900	2,148	-3,423	-266	24,142
Total	11,824,201	1,465,155	322,690	235,938	-368,417	1,655,366	-1,002,103	-76,581	12,400,883
All species	15,448,347	2,060,369	466,753	333,436	-451,917	2,408,641	-1,245,450	-113,300	16,498,238

(Table 9 continued on next page)

(Table 9 continued)

NORTHEAST

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	93,933	11,501	4,149	2,438	-4,896	13,192	-13,590	-4,528	89,007
Red pine	277,104	52,282	15,882	9,655	-222	77,597	-18,513	-1,962	334,226
White pine	208,459	30,355	1,514	3,948	-1,336	34,481	-11,583	-1,006	230,351
White spruce	72,838	24,556	3,457	2,558	-162	30,409	-5,705	-950	96,592
Black spruce	74,284	7,081	3,052	1,673	-7,900	3,906	-2,715	-875	74,600
Balsam fir	233,321	43,965	6,988	6,767	-11,753	45,967	-18,293	-5,240	255,755
Hemlock	185,917	19,729	547	2,485	-1,964	20,797	-9,321	-425	196,968
Tamarack	40,850	3,592	1,687	440	-1,913	3,806	-407	-964	43,285
Eastern redcedar	-	-	-	-	-	-	-	-	-
Northern white-cedar	249,457	22,927	12,955	3,666	-1,144	38,404	-2,941	-2,127	282,793
Other softwoods	262	116	-	45	-121	40	-	-	302
Total	1,436,425	216,104	50,231	33,675	-31,411	268,599	-83,068	-18,077	1,603,879
Hardwoods									
Select white oak	10,314	869	-	108	-	977	-1,049	-322	9,920
Select red oak	207,091	24,593	2,008	2,794	-8,823	20,572	-10,075	-2,895	214,693
Other red oak	41,188	5,095	227	568	-1,936	3,954	-1,504	-1,304	42,334
Select hickory	-	-	-	-	-	-	-	-	-
Other hickory	8,879	916	-	113	-	1,029	-	-212	9,696
Basswood	266,152	39,865	1,598	3,231	-3,319	41,375	-8,925	-332	298,270
Beech	14,667	1,167	546	226	-314	1,625	-1,730	-29	14,533
Yellow birch	87,994	7,178	948	2,141	-4,582	5,685	-7,466	-189	86,024
Hard maple	640,163	82,104	14,121	17,090	-9,774	103,541	-45,090	-579	698,035
Soft maple	302,541	43,837	10,651	6,818	-6,647	54,659	-14,244	-3,401	339,555
Elm	114,838	11,237	1,516	4,604	-10,109	7,248	-30,636	-1,340	90,110
Black ash	78,429	7,531	7,743	2,507	-3,686	14,095	-4,045	-1,887	86,592
White & green ash	71,454	9,197	1,250	1,283	-875	10,855	-3,999	-903	77,407
Cottonwood	3,839	546	-	27	-209	364	-167	-150	3,886
Willow	2,114	341	-	9	-	350	-	-126	2,338
Hackberry	-	-	-	-	-	-	-	-	-
Balsam poplar	24,302	3,637	317	340	-2,747	1,547	-525	-474	24,850
Bigtooth aspen	160,638	26,409	2,417	9,256	-9,336	28,746	-34,902	-1,765	152,717
Quaking aspen	594,941	78,569	25,189	32,051	-34,256	101,553	-149,108	-6,472	540,914
Paper birch	358,734	37,631	13,232	7,496	-7,489	50,870	-24,342	-2,832	382,430
River birch	-	-	-	-	-	-	-	-	-
Black cherry	44,580	5,274	1,213	402	-1,098	5,791	-	-251	50,120
Black walnut	-	-	-	-	-	-	-	-	-
Butternut	4,654	473	-	30	-	503	-	-9	5,148
Other hardwoods	104	-	-	6	-110	-104	-	-	-
Total	3,037,616	386,469	82,976	91,100	-105,310	455,235	-337,807	-25,472	3,129,572
All species	4,474,041	602,573	133,207	124,775	-136,721	723,834	-420,875	-43,549	4,733,451

(Table 9 continued on next page)

(Table 9 continued)

NORTHWEST

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	233,754	38,707	13,046	7,998	-10,998	48,753	-24,278	-4,063	254,166
Red pine	176,723	40,198	17,530	6,357	-232	63,853	-18,079	-645	221,852
White pine	152,354	28,304	451	1,113	-1,576	28,292	-7,087	-2,089	171,470
White spruce	118,145	41,021	2,465	3,388	-1,944	44,930	-5,398	-641	157,036
Black spruce	39,323	5,727	2,179	812	-4,781	3,937	-258	-249	42,753
Balsam fir	295,133	70,718	12,299	7,157	-14,072	76,102	-9,240	-3,952	358,043
Hemlock	63,505	8,038	-	430	-589	7,879	-518	-126	70,740
Tamarack	58,621	6,196	2,812	875	-5,082	4,801	-675	-320	62,427
Eastern redcedar	-	-	-	-	-	-	-	-	-
Northern white-cedar	116,551	12,967	2,027	1,667	-209	16,452	-3,615	-671	128,717
Other softwoods	319	105	-	-	-	105	-	-42	382
Total	1,254,428	251,981	52,809	29,797	-39,483	295,104	-69,148	-12,798	1,467,586
Hardwoods									
Select white oak	74,697	8,666	1,208	518	-325	10,067	-2,701	-1,239	80,824
Select red oak	387,993	56,123	7,461	4,809	-16,417	51,976	-15,070	-2,571	422,328
Other red oak	39,988	5,594	251	359	-1,969	4,235	-1,250	-470	42,503
Select hickory	-	-	-	-	-	-	-	-	-
Other hickory	10,146	1,040	-	146	-590	596	-	-37	10,705
Basswood	335,389	55,671	1,522	5,865	-8,219	54,839	-7,982	-723	381,523
Beech	-	-	-	-	-	-	-	-	-
Yellow birch	84,029	8,754	904	989	-4,858	5,789	-2,629	-117	87,072
Hard maple	541,264	89,958	27,725	11,297	-10,768	118,212	-22,076	-265	637,135
Soft maple	471,870	79,112	41,403	6,647	-12,433	114,729	-11,317	-2,413	572,869
Elm	139,607	18,063	533	3,667	-10,863	11,400	-21,835	-791	128,381
Black ash	223,250	20,208	11,938	2,389	-9,619	24,916	-5,830	-2,673	239,663
White & green ash	84,909	12,222	414	1,297	-1,613	12,320	-1,617	-317	95,295
Cottonwood	-	-	-	-	-	-	-	-	-
Willow	154	23	-	-	-	23	-	-	177
Hackberry	-	-	-	-	-	-	-	-	-
Balsam poplar	9,424	2,128	183	254	-721	1,844	-778	-52	10,438
Bigtooth aspen	267,280	51,468	4,691	8,326	-14,708	49,777	-41,619	-1,475	273,963
Quaking aspen	866,367	145,030	34,885	35,684	-50,067	165,532	-162,402	-5,752	863,745
Paper birch	431,742	54,837	20,508	6,926	-8,235	74,036	-25,240	-1,856	478,682
River birch	-	-	-	-	-	-	-	-	-
Black cherry	19,263	2,844	1,695	242	-178	4,603	-382	-49	23,435
Black walnut	-	-	-	-	-	-	-	-	-
Butternut	3,495	406	-	-	-	406	-	-9	3,892
Other hardwoods	213	21	-	15	-	36	-133	-	116
Total	3,991,080	612,168	155,321	89,430	-151,583	705,336	-322,861	-20,809	4,352,746
All species	5,245,508	864,149	208,130	119,227	-191,066	1,000,440	-392,009	-33,607	5,820,332

(Table 9 continued on next page)

(Table 9 continued)

CENTRAL

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	195,297	20,944	7,398	3,754	-6,756	25,340	-22,982	-3,322	194,333
Red pine	231,628	38,285	17,998	10,649	-370	66,562	-33,709	-245	264,236
White pine	169,294	24,176	1,081	2,986	-1,460	26,783	-11,195	-202	184,680
White spruce	1,155	526	263	78	-	867	-	-	2,022
Black spruce	4,158	381	676	190	-209	1,038	-1,354	-	3,842
Balsam fir	15,621	3,501	856	543	-686	4,214	-241	-34	19,560
Hemlock	25,952	3,168	-	768	-	3,936	-831	-15	29,042
Tamarack	25,616	2,182	-	116	-150	2,148	-187	-326	27,251
Eastern redcedar	491	89	-	-	-	89	-	-10	570
Northern white-cedar	31,646	2,468	1,289	1,855	-523	5,089	-	-29	36,706
Other softwoods	2,566	445	290	159	-	894	-	-	3,460
Total	703,424	96,165	29,851	21,098	-10,154	136,960	-70,499	-4,183	765,702
Hardwoods									
Select white oak	159,337	11,852	647	1,151	-	13,650	-14,992	-466	157,529
Select red oak	337,029	30,950	589	3,328	-7,639	27,228	-33,358	-803	330,096
Other red oak	315,405	26,724	974	1,732	-14,411	15,019	-19,142	-1,150	310,132
Select hickory	5,830	467	-	44	-241	270	-	-	6,100
Other hickory	12,839	987	-	730	-1,120	597	-222	-	13,214
Basswood	74,250	8,753	832	1,036	-1,115	9,506	-4,990	-52	78,714
Beech	1,117	66	-	86	-247	-95	-	-	1,022
Yellow birch	24,402	2,273	-	242	-711	1,804	-1,160	-24	25,022
Hard maple	113,434	12,146	532	1,841	-980	13,539	-10,297	-34	116,642
Soft maple	295,476	36,452	6,195	3,199	-3,902	41,944	-11,103	-1,495	324,822
Elm	44,146	5,271	490	1,180	-1,132	5,809	-9,730	-104	40,121
Black ash	66,067	5,538	4,479	618	-1,166	9,469	-3,286	-420	71,830
White & green ash	38,942	4,271	544	495	-365	4,945	-1,607	-105	42,175
Cottonwood	2,233	139	-	10	-	149	-	-9	2,373
Willow	2,937	348	-	32	-257	123	-	-18	3,042
Hackberry	-	-	-	-	-	-	-	-	-
Balsam poplar	247	-	-	4	-251	-247	-	-	-
Bigtooth aspen	152,431	23,945	2,055	1,894	-4,031	23,863	-10,259	-1,120	164,915
Quaking aspen	345,271	45,576	17,646	7,692	-12,700	58,214	-37,493	-3,560	362,432
Paper birch	122,049	12,750	8,992	977	-1,983	20,736	-3,976	-551	138,258
River birch	3,158	759	-	-	-	759	-	-13	3,904
Black cherry	17,085	1,884	1,531	147	-	3,562	-414	-91	20,142
Black walnut	409	20	-	26	-	46	-206	-	249
Butternut	5,127	521	-	57	-	578	-216	-	5,489
Other hardwoods	4,431	377	925	-353	-284	665	-638	-39	4,419
Total	2,143,652	232,069	46,431	26,168	-52,535	252,133	-163,089	-10,054	2,222,642
All species	2,847,076	328,234	76,282	47,266	-62,689	389,093	-233,588	-14,237	2,988,344

(Table 9 continued on next page)

(Table 9 continued)

SOUTHWEST

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	7,427	399	-	657	-990	66	-1,712	-556	5,225
Red pine	68,505	10,706	3,542	3,697	-211	17,734	-8,577	-	77,662
White pine	14,324	2,074	474	1,713	-	4,261	-5,149	-113	13,323
White spruce	322	87	-	-	-	87	-	-	409
Black spruce	927	59	-	-	-	59	-	-	986
Balsam fir	197	13	-	-	-	13	-	-	210
Hemlock	-	-	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-	-	-
Eastern redcedar	1,738	357	-	-	-	357	-	-4	2,091
Northern white-cedar	-	-	-	-	-	-	-	-	-
Other softwoods	-	-	-	-	-	-	-	-	-
Total	93,440	13,695	4,016	6,067	-1,201	22,577	-15,438	-673	99,906
Hardwoods									
Select white oak	279,251	18,159	741	1,070	-546	19,424	-17,903	-690	280,082
Select red oak	418,796	31,580	-	3,052	-7,109	27,523	-44,311	-1,424	400,584
Other red oak	179,055	11,388	441	993	-7,790	5,032	-20,977	-323	162,787
Select hickory	75,574	5,934	2,364	238	-961	7,575	-2,222	-241	80,686
Other hickory	36,173	3,344	3,244	139	-777	5,950	-453	-97	41,573
Basswood	120,462	12,343	1,359	893	-3,535	11,060	-6,160	-369	124,993
Beech	-	-	-	-	-	-	-	-	-
Yellow birch	1,208	112	-	-	-	112	-	-11	1,309
Hard maple	118,905	11,143	-	629	-1,205	10,567	-7,566	-400	121,506
Soft maple	95,826	10,037	1,267	439	-394	11,349	-4,269	-977	101,929
Elm	87,446	10,464	824	1,846	-4,171	8,963	-10,590	-509	85,310
Black ash	13,502	1,289	-	30	-300	1,019	-395	-187	13,939
White & green ash	46,985	4,178	1,166	227	-493	5,078	-1,462	-373	50,228
Cottonwood	19,984	1,860	-	121	-251	1,730	-811	-239	20,664
Willow	7,602	1,053	-	-	-	1,053	-	-142	8,513
Hackberry	1,421	266	-	25	-235	56	-	-26	1,451
Balsam poplar	1,186	164	-	-	-	164	-	-	1,350
Bigtooth aspen	93,513	12,832	1,050	738	-3,687	10,933	-3,816	-1,133	99,497
Quaking aspen	77,068	9,681	853	1,458	-3,223	8,769	-4,072	-1,431	80,334
Paper birch	91,481	8,798	5,012	405	-1,356	12,859	-1,810	-881	101,649
River birch	6,532	796	-	1,257	-	2,053	-1,352	-129	7,104
Black cherry	47,158	4,957	3,490	432	-292	8,587	-1,812	-211	53,722
Black walnut	16,805	1,600	-	70	-400	1,270	-495	-7	17,573
Butternut	23,340	2,270	836	98	-	3,204	-313	-128	26,103
Other hardwoods	11,075	1,065	525	218	-956	852	-892	-190	10,845
Total	1,870,348	165,313	23,172	14,378	-37,681	165,182	-131,681	-10,118	1,893,731
All species	1,963,788	179,008	27,188	20,445	-38,882	187,759	-147,119	-10,791	1,993,637

(Table 9 continued on next page)

(Table 9 continued)

SOUTHEAST

Species group	1983 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other 2/ growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	2,723	261	-	543	-	804	-1,259	-	2,268
Red pine	19,292	4,436	4,070	3,607	-	12,113	-2,051	-	29,354
White pine	16,278	3,736	382	1,221	-	5,339	-647	-54	20,916
White spruce	4,452	1,079	-	29	-	1,108	-	-	5,560
Black spruce	847	153	-	9	-	162	-	-	1,009
Balsam fir	2,363	326	308	70	-140	564	-	-66	2,861
Hemlock	2,402	259	-	27	-	286	-140	-42	2,506
Tamarack	11,561	643	633	199	-916	559	-	-117	12,003
Eastern redcedar	1,125	213	372	56	-	641	-	-	1,766
Northern white-cedar	74,860	5,830	1,391	1,100	-195	8,126	-1,097	-709	81,180
Other softwoods	526	333	-	-	-	333	-	-	859
Total	136,429	17,269	7,156	6,861	-1,251	30,035	-5,194	-988	160,282
Hardwoods									
Select white oak	110,667	6,575	-	1,170	-	7,745	-7,002	-462	110,948
Select red oak	80,300	5,389	2,384	2,657	-2,576	7,854	-7,069	-326	80,759
Other red oak	51,644	3,642	-	908	-1,778	2,772	-4,425	-285	49,706
Select hickory	36,536	2,202	728	432	-934	2,428	-1,215	-154	37,595
Other hickory	7,581	495	-	119	-213	401	-200	-37	7,745
Basswood	28,758	4,770	1,258	1,283	-2,325	4,986	-1,595	-567	31,582
Beech	13,255	967	-	16	-163	820	-258	-291	13,526
Yellow birch	6,850	485	-	60	-	545	-182	-54	7,159
Hard maple	67,400	6,034	1,117	1,456	-1,699	6,908	-3,737	-1,577	68,994
Soft maple	55,878	5,318	1,824	427	-913	6,656	-3,102	-482	58,950
Elm	42,237	3,970	468	1,465	-2,430	3,473	-7,973	-422	37,315
Black ash	36,693	2,840	1,564	120	-235	4,289	-596	-177	40,209
White & green ash	77,888	7,240	-	663	-1,708	6,195	-1,407	-909	81,767
Cottonwood	5,035	454	-	51	-	505	-340	-26	5,174
Willow	11,343	1,093	-	8	-	1,101	-	-98	12,346
Hackberry	713	77	-	-	-	77	-	-	790
Balsam poplar	3,354	551	-	-	-	551	-	-152	3,753
Bigtooth aspen	18,570	3,731	-	652	-1,007	3,376	-1,601	-329	20,016
Quaking aspen	45,569	5,602	3,855	2,322	-4,372	7,407	-1,239	-2,000	49,737
Paper birch	22,282	2,346	-	186	-230	2,302	-637	-952	22,995
River birch	-	-	-	-	-	-	-	-	-
Black cherry	40,207	3,574	1,592	652	-175	5,643	-1,945	-703	43,202
Black walnut	5,875	456	-	54	-	510	-135	-12	6,238
Butternut	3,010	210	-	27	-	237	-247	-76	2,924
Other hardwoods	9,860	1,115	-	134	-550	699	-1,760	-37	8,762
Total	781,505	69,136	14,790	14,862	-21,308	77,480	-46,665	-10,128	802,192
All species	917,934	86,405	21,946	21,723	-22,559	107,515	-51,859	-11,116	962,474

1/ Figures have been adjusted from those published after the 1983 survey to conform to changes in survey definitions and procedures.

2/ Includes growth on ingrowth, mortality and removals.

Table 10.--Sawtimber volume and periodic growth on timberland by forest type, and component of growth, Wisconsin, 1983-1987

(In thousand board feet) 1/

Forest type	1983 2/ sawtimber volume	Components							1987 sawtimber volume
		Survivor growth	Ingrowth	Other 3/ growth	Mortality	Net growth	Removals	Other removals	
Jack pine	830,785	95,830	163,391	53,994	-39,866	273,349	-182,766	-27,287	894,081
Red pine	1,561,875	253,882	358,428	54,102	-15,268	651,144	-29,262	-	2,183,757
White pine	1,396,385	189,335	65,515	48,535	-13,094	290,291	-113,181	-8,786	1,564,709
Balsam fir	806,809	138,037	137,010	45,488	-24,707	295,828	-90,521	-31,912	980,204
White spruce	220,767	56,993	59,722	14,818	-1,450	130,083	-1,054	-	349,796
Black spruce	154,019	20,841	14,606	3,492	-4,957	33,982	-1,514	-	186,487
Northern white-cedar	867,033	69,777	93,477	35,593	-19,423	179,424	-46,444	-	1,000,013
Tamarack	125,386	18,984	32,786	4,501	-3,609	52,662	-2,521	-1,701	173,826
Oak-hickory	8,689,989	672,941	619,652	222,366	-171,088	1,343,871	-1,356,108	-35,405	8,642,347
Elm-ash-soft maple	2,712,910	245,993	297,090	72,589	-88,773	526,899	-238,726	-48,193	2,952,890
Maple-basswood	12,423,149	1,364,719	1,260,912	322,443	-334,751	2,613,323	-505,939	-25,873	14,504,660
Aspen	4,027,697	576,808	929,843	471,849	-188,264	1,790,236	-1,166,080	-51,883	4,599,970
Paper birch	1,046,425	152,966	204,666	50,792	-29,979	378,445	-38,053	-5,016	1,381,801
Nonstocked	30,663	3,465	5,348	2,947	-	11,760	-6,100	-	36,323
All types	34,893,892	3,860,571	4,242,446	1,403,509	-935,229	8,571,297	-3,778,269	-236,056	39,450,864

1/ International 1/4 inch rule

2/ Figures have been adjusted from those publiched after the 1983 survey to conform to changes in survey definitions and procedures.

3/ Includes growth on ingrowth, mortality and removals.

Table 11.--Sawtimber volume and periodic growth on timberland by species group, and component of growth, Wisconsin, 1983-1987

(In thousand board feet)[1]

Species group	1983 [2] sawtimber volume	Components							1987 sawtimber volume
		Survivor growth	Ingrowth	Other [3] growth	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	1,071,691	114,054	197,791	73,404	-61,426	323,823	-206,144	-24,655	1,164,715
Red pine	1,995,540	291,096	378,669	85,784	-2,555	752,994	-240,516	-7,579	2,500,439
White pine	2,621,232	407,249	64,512	63,080	-24,392	510,449	-191,448	-15,191	2,925,042
White spruce	602,447	187,522	138,421	50,035	-3,023	372,955	-43,566	-5,593	926,243
Black spruce	97,029	11,227	11,868	3,578	-12,531	14,142	-3,973	-1,249	105,949
Balsam fir	994,391	222,632	191,744	56,292	-39,524	431,144	-46,510	-15,056	1,363,969
Hemlock	1,108,989	103,765	11,744	14,363	-10,996	118,876	-40,675	-2,134	1,185,056
Tamarack	181,540	17,806	24,284	3,776	-5,094	40,772	-4,005	-1,800	216,507
Eastern redcedar	4,005	439	946	117	-	1,502	-	-56	5,451
Northern white-cedar	1,098,281	97,250	104,330	27,967	-5,624	223,923	-31,517	-9,352	1,281,335
Other softwoods	7,647	1,140	2,003	131	-	3,274	-	-231	10,690
Total	9,782,792	1,454,180	1,126,312	378,527	-165,165	2,793,854	-808,354	-82,896	11,685,396
Hardwoods									
Select white oak	2,227,057	126,184	83,549	21,794	-2,724	228,803	-192,880	-10,733	2,252,247
Select red oak	4,595,396	423,265	315,835	97,990	-91,508	745,582	-508,325	-22,654	4,809,999
Other red oak	1,840,438	137,983	110,985	25,856	-54,375	220,449	-215,199	-10,242	1,835,446
Select hickory	283,107	14,601	17,090	5,122	-5,524	31,289	-16,247	-757	297,392
Other hickory	83,309	5,022	4,986	1,689	-	11,697	-3,260	-184	91,562
Basswood	1,978,335	234,636	302,118	62,137	-47,564	551,327	-93,539	-5,281	2,430,842
Beech	114,805	7,795	6,562	1,321	-3,139	12,539	-9,162	-1,337	116,845
Yellow birch	549,733	38,541	22,901	9,977	-30,595	40,824	-28,800	-928	560,829
Hard maple	3,369,100	345,357	283,308	116,486	-58,314	686,837	-272,140	-8,361	3,775,436
Soft maple	1,856,874	154,997	359,231	36,556	-35,068	515,716	-91,448	-17,858	2,263,284
Elm	1,172,160	101,002	78,582	58,092	-102,785	134,891	-247,891	-8,489	1,050,671
Black ash	544,167	28,298	118,694	16,038	-22,129	140,901	-35,783	-6,967	642,318
White & green ash	820,250	63,565	110,226	17,691	-11,296	180,186	-37,097	-8,048	955,291
Cottonwood	120,618	9,204	5,661	1,305	-995	15,175	-4,410	-1,515	129,868
Willow	81,779	7,744	2,690	472	-1,100	9,806	-	-1,208	90,377
Hackberry	5,989	678	-	109	-950	-163	-	-63	5,763
Balsam poplar	95,682	13,885	14,620	4,136	-10,067	22,574	-4,570	-1,978	111,708
Bigtooth aspen	1,401,901	205,220	280,000	115,513	-77,475	523,258	-272,566	-12,880	1,639,713
Quaking aspen	2,632,252	359,871	660,842	364,731	-182,661	1,202,783	-839,751	-24,154	2,971,130
Paper birch	794,774	89,042	252,614	46,900	-25,295	363,261	-66,528	-5,418	1,086,089
River birch	22,683	2,135	2,582	6,502	-	11,219	-6,365	-238	27,299
Black cherry	269,470	19,574	50,226	7,011	-	76,811	-10,137	-2,773	333,371
Black walnut	83,844	5,994	9,037	3,229	-2,445	15,815	-3,636	-109	95,914
Butternut	124,846	8,888	14,898	3,001	-	26,787	-4,329	-562	146,742
Other hardwoods	42,531	2,910	8,897	1,324	-4,055	9,076	-5,852	-423	45,332
Total	25,111,100	2,406,391	3,116,134	1,024,982	-770,064	5,777,443	-2,969,915	-153,160	27,765,468
All species	34,893,892	3,860,571	4,242,446	1,403,509	-935,229	8,571,297	-3,778,269	-236,056	39,450,864

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[1] International 1/4 inch rule.

[2] Figures have been adjusted from those published after the 1983 survey to conform to changes in survey definitions and procedures.

[3] Includes growth on ingrowth, mortality and removals.

Table 12.--Net volume of growing stock on timberland by species group and forest type, Wisconsin, 1987 and component of growth, Wisconsin, 1983-1987

(In thousand cubic feet)

Species group	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar
Softwoods								
Jack pine	544,999	389,454	22,881	10,952	594	-	347	496
Red pine	927,330	28,406	754,568	43,528	2,810	656	4,552	382
White pine	620,740	9,082	52,921	242,849	11,849	2,605	4,377	7,825
White spruce	261,619	-	4,026	5,002	35,013	106,438	977	7,011
Black spruce	123,190	241	2,181	3,151	17,691	279	56,759	13,801
Balsam fir	636,429	123	4,660	6,417	214,199	3,808	17,756	41,680
Hemlock	299,256	-	1,162	2,695	6,502	123	2,531	12,834
Tamarack	144,966	145	-	832	4,187	-	16,576	14,318
Eastern redcedar	4,427	229	-	-	-	-	-	-
Northern white-cedar	529,396	-	762	2,155	42,284	1,165	4,452	338,851
Other softwoods	5,003	-	2,422	1,099	-	-	-	-
Total	4,097,355	427,680	845,583	318,680	335,129	115,074	108,327	437,198
Hardwoods								
Select white oak	639,303	1,182	421	2,927	187	-	-	211
Select red oak	1,448,460	4,234	7,395	2,373	649	-	1,310	313
Other red oak	607,462	15,118	6,656	7,283	-	-	97	268
Select hickory	124,381	-	-	377	-	-	-	228
Other hickory	82,933	-	-	-	-	-	-	372
Basswood	915,082	87	246	406	192	211	-	1,338
Beech	29,081	-	497	-	-	-	-	-
Yellow birch	206,586	-	146	410	3,712	288	438	8,044
Hard maple	1,642,312	-	5,029	1,611	2,674	515	281	174
Soft maple	1,398,125	1,231	10,389	10,243	15,112	815	2,545	9,459
Elm	381,237	315	1,239	716	1,603	209	-	2,186
Black ash	452,233	-	-	1,044	9,350	184	-	17,877
White & green ash	346,872	-	1,389	140	131	843	-	438
Cottonwood	32,097	123	-	367	-	-	-	-
Willow	26,416	-	-	-	-	-	-	476
Hackberry	2,241	-	-	-	-	-	-	-
Balsam poplar	40,391	-	-	-	2,528	647	264	1,210
Bigtooth aspen	711,108	4,377	3,449	2,731	2,008	239	1,203	1,607
Quaking aspen	1,897,162	20,555	25,156	27,256	28,627	4,610	15,118	12,276
Paper birch	1,124,014	1,965	4,959	8,726	22,081	-	4,118	17,973
River birch	11,008	-	-	-	-	-	-	-
Black cherry	190,621	-	437	826	4,035	106	165	-
Black walnut	24,060	-	-	-	-	-	-	-
Butternut	43,556	-	-	-	-	-	-	-
Other hardwoods	24,142	-	468	-	-	-	-	-
Total	12,400,883	49,187	67,876	67,436	92,889	8,667	25,539	74,450
All species	16,498,238	476,867	913,459	386,116	428,018	123,741	133,866	511,648

(Table 12 continued on next page)

(Table 12 continued)

Species group	Tamarack	Oak-hickory	Elm-ash-soft maple	Maple-beech-birch	Aspen	Paper birch	Exotic	Nonstocked
Softwoods								
Jack pine	409	72,764	1,353	6,444	34,074	3,568	-	1,663
Red pine	522	20,030	696	17,960	37,644	15,576	-	-
White pine	7,639	46,094	25,625	137,527	52,297	19,769	-	281
White spruce	1,862	1,146	8,976	27,756	49,846	13,343	-	223
Black spruce	9,066	-	2,630	3,670	10,461	3,260	-	-
Balsam fir	7,616	1,680	54,636	118,276	127,060	38,317	-	201
Hemlock	152	1,248	17,185	245,908	5,258	3,658	-	-
Tamarack	78,829	895	11,807	4,487	8,313	3,372	-	1,205
Eastern redcedar	-	2,326	1,380	492	-	-	-	-
Northern white-cedar	1,857	274	54,206	57,992	15,505	9,893	-	-
Other softwoods	-	329	-	142	-	-	1,011	-
Total	107,952	146,786	178,494	620,654	340,458	110,756	1,011	3,573
Hardwoods								
Select white oak	-	482,670	20,768	84,497	34,512	10,256	-	1,672
Select red oak	120	911,101	17,219	309,086	135,064	58,892	-	704
Other red oak	-	491,050	8,820	28,056	43,121	3,791	-	3,202
Select hickory	-	100,213	211	18,371	1,141	3,840	-	-
Other hickory	-	40,171	977	38,810	2,603	-	-	-
Basswood	-	67,722	26,297	778,529	31,724	7,753	-	577
Beech	-	338	435	27,811	-	-	-	-
Yellow birch	252	537	18,634	167,973	3,510	2,642	-	-
Hard maple	124	36,601	15,648	1,504,322	55,438	19,756	-	139
Soft maple	3,993	103,547	311,877	624,464	242,609	61,841	-	-
Elm	231	38,105	69,749	240,304	19,419	6,181	-	980
Black ash	547	9,028	275,570	101,448	28,400	7,526	-	1,259
White & green ash	-	26,798	82,521	214,315	15,032	5,050	-	215
Cottonwood	-	6,715	16,706	4,591	3,347	248	-	-
Willow	-	445	18,789	3,575	2,090	436	-	605
Hackberry	-	896	240	920	185	-	-	-
Balsam poplar	-	1,373	6,747	4,906	21,334	1,382	-	-
Bigtooth aspen	1,814	146,069	5,061	115,509	395,762	31,279	-	-
Quaking aspen	7,148	93,179	63,472	302,272	1,203,125	90,354	-	4,014
Paper birch	6,087	111,118	43,754	208,413	289,876	403,675	-	1,269
River birch	-	1,676	9,332	-	-	-	-	-
Black cherry	-	65,717	4,178	81,473	30,052	3,632	-	-
Black walnut	-	18,681	185	4,711	-	-	-	483
Butternut	-	19,044	467	21,534	2,103	408	-	-
Other hardwoods	-	3,128	11,116	8,563	698	169	-	-
Total	20,316	2,775,922	1,028,773	4,894,453	2,561,145	719,111	-	15,119
All species	128,268	2,922,708	1,207,267	5,515,107	2,901,603	829,867	1,011	18,692

Table 13.--Net volume of sawtimber on timberland by species group and forest type, Wisconsin, 1987

(In thousand board feet)[1/]

Species group	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar
Softwoods								
Jack pine	1,164,715	720,870	52,361	34,642	3,109	-	737	-
Red pine	2,500,439	64,151	1,782,693	201,147	12,643	-	21,054	973
White pine	2,925,042	40,405	221,755	1,110,628	60,606	14,398	17,863	34,830
White spruce	926,243	-	10,874	24,769	148,349	312,433	4,381	23,602
Black spruce	105,949	635	527	4,370	18,090	605	28,755	13,687
Balsam fir	1,363,969	-	6,150	16,602	440,104	7,308	51,137	42,187
Hemlock	1,185,056	-	2,454	9,404	25,896	602	10,595	46,207
Tamarack	216,507	-	-	1,824	10,222	-	5,220	27,417
Eastern redcedar	5,451	1,389	-	-	-	-	-	-
Northern white-cedar	1,281,335	-	2,083	9,567	135,111	-	9,300	691,284
Other softwoods	10,690	-	8,076	2,614	-	-	-	-
Total	11,685,396	827,450	2,086,973	1,415,567	854,130	335,346	149,042	880,187
Hardwoods								
Select white oak	2,252,247	-	1,740	9,169	-	-	-	1,113
Select red oak	4,809,999	10,235	10,077	8,741	2,767	-	2,682	1,619
Other red oak	1,835,446	34,747	19,309	21,560	-	-	519	1,363
Select hickory	297,392	-	-	-	-	-	-	1,257
Other hickory	91,562	-	-	-	-	-	-	961
Basswood	2,430,842	-	1,106	746	968	-	-	4,838
Beech	116,845	-	1,279	-	-	-	-	-
Yellow birch	560,829	-	620	1,312	13,536	645	1,816	24,583
Hard maple	3,775,436	-	1,835	7,338	4,353	1,425	734	926
Soft maple	2,263,284	-	2,792	18,052	20,418	2,318	1,696	14,196
Elm	1,050,671	1,412	-	1,865	4,383	582	-	4,546
Black ash	642,318	-	-	3,972	12,560	1,067	-	10,429
White & green ash	955,291	-	7,528	-	-	-	-	2,366
Cottonwood	129,868	-	-	727	-	-	-	-
Willow	90,377	-	-	-	-	-	-	2,088
Hackberry	5,763	-	-	-	-	-	-	-
Balsam poplar	111,708	-	-	-	4,221	1,736	-	3,084
Bigtooth aspen	1,639,713	1,540	5,731	4,274	3,103	-	4,863	2,620
Quaking aspen	2,971,130	15,919	35,468	52,891	40,887	6,008	20,404	27,198
Paper birch	1,086,089	2,778	6,489	18,495	16,363	-	4,731	16,639
River birch	27,299	-	-	-	-	-	-	-
Black cherry	333,371	-	1,168	-	2,515	669	-	-
Black walnut	95,914	-	-	-	-	-	-	-
Butternut	146,742	-	-	-	-	-	-	-
Other hardwoods	45,332	-	1,642	-	-	-	-	-
Total	27,765,468	66,631	96,784	149,142	126,074	14,450	37,445	119,826
All species	39,450,864	894,081	2,183,757	1,564,709	980,204	349,796	186,487	1,000,013

(Table 13 continued on next page)

(Table 13 continued)

Species group	Tamarack	Oak-hickory	Elm-ash-soft maple	Maple-beech-birch	Aspen	Paper birch	Exotic	Nonstocked
Softwoods								
Jack pine	-	198,806	3,309	18,045	116,525	13,273	-	3,038
Red pine	2,916	79,967	4,027	89,518	157,545	83,805	-	-
White pine	32,757	218,869	125,369	697,878	258,423	89,924	-	1,337
White spruce	6,878	2,412	39,042	126,629	178,186	47,458	-	1,230
Black spruce	9,434	-	8,011	9,166	10,746	1,923	-	-
Balsam fir	11,206	649	120,140	308,222	273,050	87,214	-	-
Hemlock	403	4,932	52,020	997,967	21,381	13,195	-	-
Tamarack	81,287	2,354	44,388	13,359	19,631	6,157	-	4,648
Eastern redcedar	-	945	1,063	2,054	-	-	-	-
Northern white-cedar	3,689	-	153,653	216,393	33,401	26,854	-	-
Other softwoods	-	-	-	-	-	-	-	-
Total	148,570	508,934	551,022	2,479,231	1,068,888	369,803	-	10,253
Hardwoods								
Select white oak	-	1,734,910	74,362	320,016	77,625	28,730	-	4,582
Select red oak	586	3,125,749	64,287	1,103,053	282,787	193,819	-	3,597
Other red oak	-	1,467,101	33,091	101,785	137,263	12,560	-	6,148
Select hickory	-	233,600	1,012	50,410	-	11,113	-	-
Other hickory	-	37,764	981	50,790	1,066	-	-	-
Basswood	-	180,494	64,200	2,102,122	61,840	12,947	-	1,581
Beech	-	-	840	114,726	-	-	-	-
Yellow birch	680	1,269	41,236	466,721	3,004	5,407	-	-
Hard maple	-	92,787	24,245	3,580,140	36,295	25,358	-	-
Soft maple	4,735	149,624	808,021	1,046,097	149,072	46,263	-	-
Elm	618	94,812	199,243	682,838	48,607	9,119	-	2,646
Black ash	-	15,451	421,846	147,092	19,767	10,134	-	-
White & green ash	-	71,844	255,552	582,331	23,283	11,160	-	1,227
Cottonwood	-	28,498	69,544	20,046	9,893	1,160	-	-
Willow	-	1,353	67,255	14,184	2,582	1,828	-	1,087
Hackberry	-	3,629	978	1,156	-	-	-	-
Balsam poplar	-	3,683	22,413	18,611	55,334	2,626	-	-
Bigtooth aspen	3,478	361,273	16,234	312,573	831,325	92,699	-	-
Quaking aspen	8,528	147,330	129,123	750,615	1,552,922	179,973	-	3,864
Paper birch	6,631	96,555	57,124	300,503	197,864	361,917	-	-
River birch	-	4,662	22,637	-	-	-	-	-
Black cherry	-	133,543	2,833	155,744	31,714	5,185	-	-
Black walnut	-	81,744	-	12,832	-	-	-	1,338
Butternut	-	60,543	1,384	77,090	7,725	-	-	-
Other hardwoods	-	5,195	23,427	13,954	1,114	-	-	-
Total	25,256	8,133,413	2,401,868	12,025,429	3,531,082	1,011,998	-	26,070
All species	173,826	8,642,347	2,952,890	14,504,660	4,599,970	1,381,801	-	36,323

1/ International 1/4-inch rule

Table 14.--Net volume of growing stock on timberland by species group and diameter class, Wisconsin, 1987

(In thousand cubic feet)

Species group	All classes	Diameter class(inches at breast height) 5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods												
Jack pine	544,999	143,742	177,445	132,597	67,802	18,181	4,626	606	-	-	-	-
Red pine	927,330	231,280	259,016	162,993	99,875	52,613	40,988	35,103	27,815	10,104	7,523	20
White pine	620,740	26,853	47,023	55,077	58,450	65,629	72,704	75,572	62,012	41,919	86,302	29,199
White spruce	261,619	23,895	48,357	65,690	47,339	29,880	19,833	12,840	8,141	2,461	2,969	214
Black spruce	123,190	60,748	39,116	14,987	5,834	999	786	556	164	-	-	-
Balsam fir	636,429	158,260	174,925	151,394	91,675	38,083	13,651	7,147	1,294	-	-	-
Hemlock	299,256	8,330	20,259	32,825	36,140	43,488	38,450	40,375	28,294	19,092	28,666	3,337
Tamarack	144,966	53,801	50,380	19,658	11,488	4,598	2,272	1,786	983	-	-	-
Eastern redcedar	4,427	2,460	1,014	425	185	186	157	-	-	-	-	-
Northern white-cedar	529,396	131,471	145,590	103,729	79,881	35,292	21,028	7,889	2,288	1,416	812	-
Other softwoods	5,003	2,091	861	678	1,044	-	329	-	-	-	-	-
Total	4,097,355	842,931	963,986	740,053	499,713	288,949	214,824	181,874	130,991	74,992	126,272	32,770
Hardwoods												
Select white oak	639,303	43,525	69,760	84,094	94,218	90,218	78,673	58,496	42,161	26,099	37,428	14,631
Select red oak	1,448,460	87,635	168,476	215,362	228,083	199,567	162,874	129,032	94,449	56,524	84,028	22,430
Other red oak	607,462	40,070	81,503	102,540	99,619	91,413	74,123	48,565	29,118	17,788	19,188	3,535
Select hickory	124,381	17,790	21,930	27,785	22,971	15,514	9,102	5,719	2,034	894	642	-
Other hickory	82,933	28,132	25,794	10,864	10,078	4,531	2,169	675	484	-	206	-
Basswood	915,082	71,480	142,440	195,585	184,437	120,452	77,013	46,018	30,720	16,419	23,175	7,343
Beech	29,081	2,095	2,064	2,485	4,500	4,130	3,451	4,076	2,436	2,238	1,606	-
Yellow birch	206,586	18,867	30,289	38,043	33,073	25,135	19,957	18,623	10,132	5,717	5,684	1,066
Hard maple	1,642,312	292,272	317,038	276,290	198,802	147,925	120,770	103,639	77,375	40,388	55,358	12,455
Soft maple	1,398,125	374,911	340,557	241,627	150,502	104,213	66,547	36,589	27,615	20,045	23,765	11,754
Elm	381,237	29,814	48,115	66,524	71,636	54,898	44,896	28,047	13,343	7,928	11,022	5,014
Black ash	452,233	141,765	117,915	84,776	51,808	29,482	14,646	6,816	2,131	1,235	1,659	-
White & green ash	346,872	41,388	56,413	70,028	68,047	44,259	31,926	15,484	7,701	4,686	6,196	744
Cottonwood	32,097	515	1,224	886	3,729	3,423	2,529	3,650	2,959	1,498	2,743	8,941
Willow	26,416	728	1,432	2,965	2,537	4,402	3,349	5,170	1,888	1,369	2,309	267
Hackberry	2,241	431	171	343	485	-	546	-	-	-	265	-
Balsam poplar	40,391	3,328	5,656	6,179	7,395	7,139	5,371	2,135	1,479	908	801	-
Bigtooth aspen	711,108	65,463	112,288	178,402	169,710	103,161	50,994	21,102	4,911	1,885	2,955	237
Quaking aspen	1,897,162	357,394	468,861	467,281	325,666	166,250	73,232	27,192	9,043	2,070	173	-
Paper birch	1,124,014	291,366	373,721	244,633	133,424	55,373	18,867	5,143	1,397	-	90	-
River birch	11,008	1,003	2,127	2,031	1,440	1,754	922	-	553	574	604	-
Black cherry	190,621	46,265	44,768	39,233	24,745	18,157	8,757	3,956	3,606	712	422	-
Black walnut	24,060	2,211	1,897	3,081	5,668	4,107	1,871	2,049	2,038	889	249	-
Butternut	43,556	4,505	5,439	7,196	8,538	7,588	4,884	2,718	1,253	575	597	263
Other hardwoods	24,142	5,239	5,671	5,055	3,799	2,727	618	672	151	-	210	-
Total	12,400,883	1,968,192	2,445,549	2,373,288	1,904,910	1,305,818	878,087	575,566	368,977	210,441	281,375	88,680
All species	16,498,238	2,811,123	3,409,535	3,113,341	2,404,623	1,594,767	1,092,911	757,440	499,968	285,433	407,647	121,450

Table 15.--Net volume of sawtimber on timberland by species group and diameter class, Wisconsin, 1987

(In thousand board feet)[1/]

Species group	All classes	Diameter class(inches at breast height) 9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	1,164,715	688,699	352,311	95,860	24,653	3,192	-	-	-	-
Red pine	2,500,439	939,807	564,371	298,194	233,604	201,512	160,405	58,652	43,777	117
White pine	2,925,042	219,864	274,448	333,392	389,905	416,813	354,692	244,138	512,334	179,456
White spruce	926,243	296,314	230,556	150,447	104,831	68,348	44,590	13,524	16,473	1,160
Black spruce	105,949	64,325	28,218	5,075	4,324	3,088	919	-	-	-
Balsam fir	1,363,969	635,883	424,710	188,525	69,967	37,672	7,212	-	-	-
Hemlock	1,185,056	115,538	144,460	186,288	171,970	185,968	132,970	91,239	139,985	16,638
Tamarack	216,507	102,137	60,919	25,179	12,670	10,016	5,586	-	-	-
Eastern redcedar	5,451	2,452	1,014	1,040	945	-	-	-	-	-
Northern white-cedar	1,281,335	506,708	407,297	185,682	113,180	43,118	12,758	7,983	4,609	-
Other softwoods	10,690	2,938	5,835	-	1,917	-	-	-	-	-
Total	11,685,396	3,574,665	2,494,139	1,469,682	1,127,966	969,727	719,132	415,536	717,178	197,371
Hardwoods										
Select white oak	2,252,247	-	518,080	467,142	394,199	287,907	205,990	126,588	181,413	70,928
Select red oak	4,809,999	-	1,107,999	968,324	793,435	637,652	471,545	283,944	430,335	116,765
Other red oak	1,835,446	-	475,103	433,129	352,960	232,972	141,257	86,861	95,274	17,890
Select hickory	297,392	-	127,210	80,129	45,223	27,493	9,955	4,313	3,069	-
Other hickory	91,562	-	51,999	22,348	10,679	3,257	2,318	-	961	-
Basswood	2,430,842	-	866,857	574,122	372,395	225,774	152,823	82,505	118,078	38,288
Beech	116,845	-	24,150	21,925	17,485	20,930	12,537	11,467	8,351	-
Yellow birch	560,829	-	134,622	114,275	96,578	94,125	52,924	30,518	31,666	6,121
Hard maple	3,775,436	-	939,391	720,567	603,679	528,582	402,205	213,485	298,338	69,189
Soft maple	2,263,284	-	840,445	536,652	325,691	173,721	129,118	93,180	110,072	54,405
Elm	1,050,671	-	307,878	238,910	199,902	127,092	61,694	37,162	52,961	25,072
Black ash	642,318	-	328,955	171,841	79,964	35,871	10,906	6,406	8,375	-
White & green ash	955,291	-	392,208	235,129	160,244	75,970	37,074	22,222	28,985	3,459
Cottonwood	129,868	-	15,826	14,060	10,509	15,480	12,759	6,590	12,375	42,269
Willow	90,377	-	10,456	17,953	13,987	22,057	8,235	6,004	10,460	1,225
Hackberry	5,763	-	2,095	-	2,439	-	-	-	1,229	-
Balsam poplar	111,708	-	29,850	31,243	24,659	10,225	7,182	4,525	4,024	-
Bigtooth aspen	1,639,713	-	761,523	480,540	244,055	103,480	24,271	9,488	15,119	1,237
Quaking aspen	2,971,130	-	1,536,046	837,894	385,566	148,122	50,654	11,816	1,032	-
Paper birch	1,086,089	-	662,811	286,313	100,464	28,083	7,907	-	511	-
River birch	27,299	-	6,673	8,178	4,346	-	2,578	2,720	2,804	-
Black cherry	333,371	-	144,296	99,628	45,478	20,295	18,035	3,553	2,086	-
Black walnut	95,914	-	35,068	23,372	10,312	10,760	10,637	4,515	1,250	-
Butternut	146,742	-	50,752	42,447	25,705	14,042	6,592	2,904	3,003	1,297
Other hardwoods	45,332	-	20,828	15,214	3,458	3,755	877	-	1,200	-
Total	27,765,468	-	9,391,121	6,441,335	4,323,412	2,847,645	1,840,073	1,050,766	1,422,971	448,145
All species	39,450,864	3,574,665	11,885,260	7,911,017	5,451,378	3,817,372	2,559,205	1,466,302	2,140,149	645,516

1/ International 1/4-inch rule

Table 16.--Annual net growth, mortality and removals of growing stock and sawtimber on timberland by softwoods and harwoods, Wisconsin, 1982 and 1986

Species group	Growing stock 1982	Growing stock 1986	Sawtimber 1982	Sawtimber 1986
	Thousand cubic feet		Thousand board feet[1]	
NET GROWTH				
Softwoods	142,663	179,860	458,941	638,291
Hardwoods	348,753	391,467	984,078	1,368,200
All species	491,236	571,327	1,443,019	2,006,490
MORTALITY				
Softwoods	22,051	18,856	41,795	38,198
Hardwoods	114,717	85,824	209,988	179,850
All species	136,768	104,680	251,783	218,056
REMOVALS				
Softwoods	59,388	63,766	133,652	143,743
Hardwoods	225,570	264,911	692,675	811,143
All species	284,958	328,677	826,327	954,886

[1] International 1/4 inch rule

Table 17.--Net volume in short-log trees on timberland by species group and diameter class, Wisconsin, 1987

(In thousand cubic feet)

Species group	All classes	Diameter class(inches at breast height) 9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	5,447	1,272	1,375	455	2,345	-	-	-	-	-
Red pine	631	179	72	190	-	190	-	-	-	-
White pine	10,481	667	2,140	1,751	405	649	490	846	1,838	1,695
White spruce	385	-	158	227	-	-	-	-	-	-
Black spruce	184	184	-	-	-	-	-	-	-	-
Balsam fir	1,257	594	154	194	-	315	-	-	-	-
Hemlock	4,947	488	775	1,090	693	636	589	351	175	150
Tamarack	573	134	237	202	-	-	-	-	-	-
Northern white-cedar	8,523	3,362	3,111	1,111	723	106	110	-	-	-
Total	32,428	6,880	8,022	5,220	4,166	1,896	1,189	1,197	2,013	1,845
Hardwoods										
Select white oak	50,312	-	3,968	9,047	10,240	7,920	5,925	3,810	7,149	2,253
Select red oak	47,620	-	1,991	7,672	9,839	7,507	5,181	3,191	9,261	2,978
Other red oak	53,502	-	4,614	10,057	9,774	11,941	6,337	3,841	5,936	1,002
Select hickory	3,842	-	316	1,369	1,484	673	-	-	-	-
Other hickory	1,348	-	1,166	182	-	-	-	-	-	-
Basswood	15,152	-	1,830	2,295	2,699	2,479	1,969	1,066	1,304	1,510
Beech	1,299	-	-	-	200	376	151	-	216	356
Yellow birch	8,057	-	1,396	2,330	1,509	925	756	335	704	102
Hard maple	41,366	-	3,551	9,264	7,360	7,091	4,003	3,290	4,914	1,893
Soft maple	34,383	-	3,549	7,090	5,017	4,522	3,076	3,729	2,547	4,853
Elm	19,838	-	2,147	3,940	3,842	3,142	2,166	1,168	1,514	1,919
Black ash	1,491	-	523	536	354	-	78	-	-	-
White & green ash	5,677	-	642	1,717	1,111	850	66	255	1,036	-
Cottonwood	1,486	-	265	-	275	-	189	-	248	509
Willow	3,243	-	211	611	609	-	412	206	913	281
Balsam poplar	389	-	-	-	-	389	-	-	-	-
Bigtooth aspen	4,601	-	638	1,525	638	1,220	580	-	-	-
Quaking aspen	10,964	-	2,846	3,934	3,381	389	156	258	-	-
Paper birch	8,423	-	2,164	3,940	1,261	572	377	109	-	-
River birch	726	-	-	-	425	-	301	-	-	-
Black cherry	5,671	-	453	2,625	1,121	466	-	507	499	-
Black walnut	523	-	229	-	-	294	-	-	-	-
Butternut	2,466	-	346	643	736	298	216	-	227	-
Other hardwoods	2,277	-	649	106	801	416	-	-	148	157
Total	324,656	-	33,494	68,883	62,676	51,470	31,939	21,765	36,616	17,813
All species	357,084	6,880	41,516	74,103	66,842	53,366	33,128	22,962	38,629	19,658

Table 18.--Net volume in short-log trees on timberland by species group and diameter class, Wisconsin, 1987

(In thousand board feet)[1/]

Species group	All classes	Diameter class(inches at breast height)							
		9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	18,769	4,417	4,723	1,574	8,055	-	-	-	-	-
Red pine	2,570	710	286	751	-	823	-	-	-	-
White pine	37,159	1,693	6,414	5,909	1,439	2,435	1,839	3,331	7,234	6,865
White spruce	1,757	-	694	1,063	-	-	-	-	-	-
Black spruce	482	482	-	-	-	-	-	-	-	-
Balsam fir	3,400	1,465	400	549	-	986	-	-	-	-
Hemlock	12,016	968	1,736	2,597	1,710	1,642	1,550	926	472	415
Tamarack	2,469	538	1,032	899	-	-	-	-	-	-
Northern white-cedar	29,346	11,106	10,713	3,980	2,725	394	428	-	-	-
Total	107,968	21,379	25,998	17,322	13,929	6,280	3,817	4,257	7,706	7,280
Hardwoods										
Select white oak	132,401	-	11,362	24,650	26,999	20,536	15,159	9,718	18,211	5,766
Select red oak	108,442	-	4,374	17,128	22,076	16,912	11,750	7,403	21,718	7,081
Other red oak	123,431	-	10,405	22,960	22,369	27,415	14,765	9,003	14,118	2,396
Select hickory	10,405	-	938	3,754	3,937	1,776	-	-	-	-
Other hickory	3,623	-	3,171	452	-	-	-	-	-	-
Basswood	33,020	-	3,780	4,869	5,817	5,406	4,327	2,367	2,921	3,533
Beech	3,503	-	-	-	552	1,041	391	-	585	934
Yellow birch	19,059	-	2,870	5,183	3,644	2,326	1,948	883	1,910	295
Hard maple	101,592	-	8,123	21,926	17,806	17,498	10,036	8,409	12,764	5,030
Soft maple	91,317	-	10,557	19,674	13,400	11,853	7,851	9,448	6,393	12,141
Elm	51,105	-	5,260	9,787	9,687	8,212	5,674	2,999	4,048	5,438
Black ash	4,231	-	1,667	1,474	875	-	215	-	-	-
White & green ash	13,301	-	1,585	4,182	2,564	1,953	197	567	2,253	-
Cottonwood	4,807	-	793	-	828	-	587	-	839	1,760
Willow	10,068	-	600	1,783	1,862	-	1,284	652	2,933	954
Balsam poplar	985	-	-	-	-	985	-	-	-	-
Bigtooth aspen	7,739	-	1,006	2,526	1,077	2,131	999	-	-	-
Quaking aspen	25,059	-	6,118	8,881	8,053	980	382	645	-	-
Paper birch	23,212	-	5,816	10,771	3,545	1,637	1,110	333	-	-
River birch	2,421	-	-	-	1,410	-	1,011	-	-	-
Black cherry	14,808	-	1,285	6,974	2,897	1,176	-	1,234	1,242	-
Black walnut	1,410	-	632	-	-	778	-	-	-	-
Butternut	6,540	-	965	1,780	1,938	771	534	-	552	-
Other hardwoods	8,255	-	2,342	394	2,852	1,508	-	-	555	604
Total	800,734	-	83,649	169,148	154,188	124,894	78,220	53,661	91,042	45,932
All species	908,702	21,379	109,647	186,470	168,117	131,174	82,037	57,918	98,748	53,212

[1/] International 1/4-inch rule

Table 19.--All live tree biomass on timberland by species group and tree biomass component, Wisconsin, 1987

ALL UNITS

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops, limbs, and stumps	Bole	Tops, limbs, and stumps		
	Green tons						Pounds
Softwoods							
Jack pine	23,260,135	14,366,365	2,900,031	1,262,171	246,136	4,485,432	46
Red pine	30,806,168	23,322,669	4,382,523	305,155	58,903	2,736,918	46
White pine	23,174,697	16,772,683	2,900,964	1,225,484	217,876	2,057,690	45
White spruce	9,995,417	6,381,820	2,328,668	193,155	72,971	1,018,803	45
Black spruce	9,345,748	3,057,448	1,322,779	104,821	45,557	4,815,143	45
Balsam fir	34,243,285	16,941,265	6,910,033	423,338	163,462	9,805,187	47
Hemlock	14,098,935	9,456,037	2,983,103	841,057	288,084	530,654	51
Tamarack	7,892,839	4,259,717	923,565	248,017	54,117	2,407,423	52
Eastern redcedar	439,536	99,154	45,381	74,655	31,818	188,528	43
Northern white-cedar	22,507,878	10,836,049	4,720,954	1,994,782	826,810	4,129,283	36
Other softwoods	313,962	110,245	46,086	48,173	17,824	91,634	44
Total	176,078,600	105,603,452	29,464,087	6,720,808	2,023,558	32,266,695	45
Hardwoods							
Select white oak	45,865,798	23,135,189	9,362,252	7,630,542	2,984,155	2,753,660	58
Select red oak	89,846,709	55,878,239	21,172,378	8,276,134	2,985,123	1,534,835	64
Other red oak	52,122,856	24,051,922	9,626,920	12,025,194	4,723,593	1,695,227	64
Select hickory	8,307,658	4,591,914	1,914,667	889,358	370,153	541,566	63
Other hickory	5,329,127	2,796,395	1,265,779	258,629	108,074	900,250	59
Basswood	38,591,764	23,307,396	9,419,335	2,712,211	1,016,038	2,136,784	42
Beech	2,121,628	985,687	364,866	444,126	157,756	169,193	59
Yellow birch	16,955,529	7,711,807	3,157,886	2,947,473	1,186,678	1,951,685	61
Hard maple	115,244,061	59,984,481	24,401,321	12,334,777	4,729,905	13,793,577	63
Soft maple	93,792,692	43,926,017	18,733,718	9,602,903	3,790,244	17,739,810	55
Elm	25,491,300	12,747,371	5,322,295	3,042,071	1,238,600	3,140,963	55
Black ash	24,839,299	12,847,046	5,963,939	1,004,945	459,879	4,563,490	50
White & green ash	18,289,730	10,757,025	4,344,749	1,281,980	497,091	1,408,885	51
Cottonwood	1,512,177	1,000,243	333,525	108,548	37,424	32,437	51
Willow	1,780,358	776,350	290,389	429,111	146,659	137,849	48
Hackberry	131,127	71,826	31,626	5,152	2,635	19,888	52
Balsam poplar	2,051,569	1,300,239	487,445	92,737	31,196	139,952	53
Bigtooth aspen	32,106,591	21,771,176	6,557,916	1,479,021	421,026	1,877,452	50
Quaking aspen	101,318,292	56,554,222	18,593,796	7,456,026	2,334,985	16,379,263	50
Paper birch	64,783,034	35,699,003	15,780,745	3,632,531	1,553,591	8,117,164	55
River birch	801,726	371,692	146,482	129,300	46,750	107,502	55
Black cherry	13,491,425	5,249,469	2,242,155	2,357,476	1,018,549	2,623,776	49
Black walnut	1,395,998	797,581	310,353	200,252	77,150	10,662	54
Butternut	2,639,531	1,179,276	464,419	630,384	247,970	117,482	45
Other hardwoods	3,153,307	670,208	300,786	970,167	414,422	797,724	46
Noncommercial spp.	10,345,447	-	-	2,237,592	1,166,354	6,941,501	50
Total	772,308,733	408,161,774	160,589,742	82,178,640	31,746,000	89,632,577	56
All species	948,387,333	513,765,226	190,053,829	88,899,448	33,769,558	121,899,272	53

(Table 19 continued on next page)

(Table 19 continued)

NORTHEAST

Species group	All components	Component: Growing stock: Bole	Component: Growing stock: Tops, limbs, and stumps	Component: Cull: Bole	Component: Cull: Tops, limbs, and stumps	Component: 1- to 5-inch trees	Average weight per cubic foot (including bark)
	- - - - - - - - -	- - - - Green	tons - - - -	- - - -	- - - -	- - - -	- Pounds -
Softwoods							
Jack pine	3,716,284	2,351,921	466,616	351,541	67,662	478,544	46
Red pine	11,045,662	8,556,427	1,570,045	79,090	14,758	825,342	46
White pine	8,191,867	6,200,568	1,033,268	316,279	57,983	583,769	45
White spruce	3,587,932	2,337,051	860,747	118,781	45,268	226,085	45
Black spruce	5,024,579	1,867,894	805,428	44,493	17,979	2,288,785	45
Balsam fir	14,193,827	6,872,708	2,848,672	152,799	61,172	4,258,476	47
Hemlock	8,965,727	6,218,466	1,905,313	317,730	111,941	412,277	51
Tamarack	2,550,182	1,266,762	281,509	62,729	14,020	925,162	52
Eastern redcedar	3,050	-	-	1,984	1,066	-	43
Northern white-cedar	11,865,700	5,716,534	2,541,840	882,320	374,655	2,350,351	36
Other softwoods	50,303	5,628	2,406	32,023	10,246	-	44
Total	69,195,113	41,393,959	12,315,844	2,359,769	776,750	12,348,791	45
Hardwoods							
Select white oak	575,594	359,996	153,868	20,838	8,361	32,531	58
Select red oak	12,557,251	8,271,853	3,234,592	604,678	242,237	203,891	64
Other red oak	3,047,672	1,659,888	677,848	425,270	173,648	111,018	64
Select hickory	-	-	-	-	-	-	-
Other hickory	619,575	339,355	146,125	23,254	9,635	101,206	59
Basswood	11,752,719	7,610,447	3,143,669	290,774	124,231	583,598	42
Beech	989,302	479,822	173,590	180,570	62,951	92,369	59
Yellow birch	6,377,665	3,205,100	1,270,822	778,599	307,372	815,772	61
Hard maple	45,360,343	25,671,130	10,432,740	2,953,363	1,177,008	5,126,102	63
Soft maple	21,666,979	10,803,286	4,728,144	1,378,124	568,109	4,189,316	55
Elm	5,645,530	3,005,002	1,252,070	402,291	166,717	819,450	55
Black ash	5,106,019	2,368,618	1,109,506	207,863	97,623	1,322,409	50
White & green ash	3,729,533	2,383,628	966,746	102,577	44,996	231,586	51
Cottonwood	190,366	120,639	45,231	-	-	24,496	51
Willow	151,087	69,079	25,501	10,010	3,923	42,574	48
Hackberry	-	-	-	-	-	-	-
Balsam poplar	1,142,269	798,578	301,637	16,166	6,018	19,870	53
Bigtooth aspen	7,159,411	4,655,298	1,418,569	451,858	137,570	496,116	50
Quaking aspen	29,498,233	16,059,929	5,247,393	1,709,791	527,976	5,953,144	50
Paper birch	20,937,326	12,252,858	5,389,490	797,597	345,087	2,152,294	55
River birch	-	-	-	-	-	-	-
Black cherry	3,479,135	1,414,260	618,593	500,650	225,774	719,858	49
Black walnut	-	-	-	-	-	-	-
Butternut	204,420	142,472	53,347	5,828	2,773	-	45
Other hardwoods	782	-	-	-	-	782	46
Noncommercial spp.	1,687,117	-	-	423,719	222,843	1,040,555	50
Total	181,878,328	101,671,238	40,389,481	11,283,820	4,454,852	24,078,937	55
All species	251,073,441	143,065,197	52,705,325	13,643,589	5,231,602	36,427,728	52

(Table 19 continued on next page)

(Table 19 continued)

NORTHWEST

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops, limbs, and stumps	Bole	Tops, limbs, and stumps		
	- - - - - - - -	- - - - - - - -	- - - - Green tons	- - - - - - - -	- - - - - - - -	- - - - - - - -	- Pounds -
Softwoods							
Jack pine	10,394,253	6,612,315	1,346,000	436,556	85,989	1,913,393	46
Red pine	7,115,212	5,401,940	980,312	76,308	14,350	642,302	46
White pine	6,158,989	4,637,774	781,125	399,671	64,990	275,429	45
White spruce	5,806,524	3,851,851	1,390,186	74,374	27,703	462,410	45
Black spruce	3,919,176	1,055,925	457,572	60,328	27,578	2,317,773	45
Balsam fir	18,581,262	9,477,330	3,806,235	235,974	89,872	4,971,851	47
Hemlock	3,591,799	2,238,737	726,797	402,092	136,603	87,570	51
Tamarack	3,433,780	1,813,246	392,800	146,817	31,878	1,049,039	52
Eastern redcedar	-	-	-	-	-	-	-
Northern white-cedar	5,562,576	2,676,407	1,103,130	850,452	343,665	588,922	36
Other softwoods	12,144	8,830	3,314	-	-	-	44
Total	64,575,715	37,774,355	10,987,471	2,682,572	822,628	12,308,689	46
Hardwoods							
Select white oak	5,777,175	2,866,983	1,243,494	692,180	275,308	699,210	58
Select red oak	25,960,822	16,040,044	6,543,023	1,962,011	769,833	645,911	64
Other red oak	3,895,586	1,670,316	690,187	953,675	385,875	195,533	64
Select hickory	-	-	-	-	-	-	-
Other hickory	765,000	374,011	166,675	54,549	21,271	148,494	59
Basswood	15,690,466	9,747,107	3,987,689	889,896	351,980	713,794	42
Beech	-	-	-	-	-	-	-
Yellow birch	7,734,282	3,236,779	1,335,927	1,646,264	668,411	846,901	61
Hard maple	48,028,994	22,800,836	9,676,165	5,967,370	2,397,299	7,187,324	63
Soft maple	40,041,026	17,409,868	7,688,276	4,381,234	1,829,505	8,732,143	55
Elm	7,739,699	4,311,556	1,768,739	766,378	311,138	581,888	55
Black ash	13,058,571	6,856,926	3,198,860	521,737	241,713	2,239,335	50
White & green ash	4,753,002	2,970,391	1,221,083	294,202	116,030	151,296	51
Cottonwood	1,509	-	-	-	-	1,509	51
Willow	32,593	5,291	2,082	13,777	4,288	7,155	48
Hackberry	-	-	-	-	-	-	-
Balsam poplar	626,091	332,380	130,893	45,720	16,642	100,456	53
Bigtooth aspen	12,326,949	8,319,080	2,518,502	617,861	173,678	697,828	50
Quaking aspen	46,057,535	25,805,936	8,413,634	3,849,194	1,200,779	6,787,992	50
Paper birch	27,090,019	15,150,737	6,720,100	1,513,343	649,410	3,056,429	55
River birch	-	-	-	-	-	-	-
Black cherry	2,049,912	631,716	279,950	533,344	238,299	366,603	49
Black walnut	7,380	-	-	5,368	2,012	-	54
Butternut	267,495	107,480	42,972	54,879	20,784	41,380	45
Other hardwoods	25,605	3,353	1,517	14,328	6,407	-	46
Noncommercial spp.	3,028,577	-	-	508,136	263,019	2,257,422	50
Total	264,958,288	138,640,790	55,629,768	25,285,446	9,943,681	35,458,603	55
All species	329,534,003	176,415,145	66,617,239	27,968,018	10,766,309	47,767,292	53

(Table 19 continued on next page)

(Table 19 continued)

CENTRAL

Species group	All components	Component: Growing stock: Bole	Component: Growing stock: Tops, limbs, and stumps	Component: Cull: Bole	Component: Cull: Tops, limbs, and stumps	Component: 1- to 5-inch trees	Average weight per cubic foot (including bark)
	- - -	- - -	- - - Green tons	- - -	- - -	- - -	- Pounds -
Softwoods							
Jack pine	8,821,953	5,190,195	1,045,698	427,009	84,211	2,074,840	46
Red pine	9,193,821	6,665,759	1,302,585	114,988	22,714	1,087,775	46
White pine	7,219,939	5,037,023	901,612	470,108	85,830	725,366	45
White spruce	271,193	41,465	17,477	-	-	212,251	45
Black spruce	262,224	82,098	36,297	-	-	143,829	45
Balsam fir	1,227,784	515,595	222,478	31,396	10,683	447,632	47
Hemlock	1,421,936	919,214	317,570	118,604	38,224	28,324	51
Tamarack	1,401,796	830,356	180,359	33,171	7,160	350,750	52
Eastern redcedar	50,384	14,178	6,115	9,815	3,781	16,495	43
Northern white-cedar	1,820,779	751,567	344,396	78,476	31,966	614,374	36
Other softwoods	228,554	79,791	33,401	16,150	7,578	91,634	44
Total	31,920,363	20,127,241	4,407,988	1,299,717	292,147	5,793,270	46
Hardwoods							
Select white oak	12,126,603	5,702,103	2,455,431	1,947,537	805,861	1,215,671	58
Select red oak	20,965,674	12,854,172	4,845,136	2,181,049	787,913	297,404	64
Other red oak	28,034,567	12,274,486	5,089,143	6,773,534	2,756,878	1,140,526	64
Select hickory	526,211	230,264	91,608	105,989	44,444	53,906	63
Other hickory	849,029	468,605	203,880	42,786	17,353	116,405	59
Basswood	3,512,308	1,998,869	783,240	364,196	135,658	230,345	42
Beech	85,893	34,966	13,810	28,259	8,858	-	59
Yellow birch	2,260,682	947,439	409,383	441,716	179,818	282,326	61
Hard maple	8,481,852	4,374,297	1,688,957	1,245,349	447,296	725,953	63
Soft maple	22,086,960	10,497,881	4,380,095	2,391,971	902,537	3,914,476	55
Elm	3,012,938	1,339,958	580,751	378,696	159,496	554,037	54
Black ash	3,729,253	2,028,584	931,673	128,712	57,421	582,863	50
White & green ash	2,441,271	1,305,558	533,492	268,518	105,608	228,095	51
Cottonwood	131,653	74,122	22,844	26,376	8,311	-	51
Willow	165,804	88,590	31,777	25,738	8,926	10,773	48
Hackberry	-	-	-	-	-	-	-
Balsam poplar	-	-	-	-	-	-	-
Bigtooth aspen	7,373,436	5,097,247	1,558,605	186,411	49,774	481,399	50
Quaking aspen	18,803,011	10,762,781	3,648,719	1,181,779	375,387	2,834,345	50
Paper birch	9,395,359	4,311,829	1,965,360	706,994	315,119	2,096,057	55
River birch	302,928	130,780	51,569	63,621	25,174	31,784	55
Black cherry	2,004,187	539,168	237,099	341,501	155,078	731,341	49
Black walnut	35,622	8,281	3,037	18,201	6,103	-	54
Butternut	322,487	152,491	56,244	81,219	31,079	1,454	45
Other hardwoods	422,299	114,200	51,727	101,402	45,277	109,693	46
Noncommercial spp.	1,431,862	-	-	245,340	126,712	1,059,810	50
Total	148,501,889	75,336,671	29,633,580	19,276,894	7,556,081	16,698,663	57
All species	180,422,252	95,463,912	34,041,568	20,576,611	7,848,228	22,491,933	54

(Table 19 continued on next page)

(Table 19 continued)

SOUTHWEST

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops, limbs, and stumps	Bole	Tops, limbs, and stumps		
	- - - - - -	- - - - - -	- - - -	Green tons	- - - - - -	- - - - - -	- Pounds -
Softwoods							
Jack pine	250,875	149,413	27,468	47,065	8,274	18,655	46
Red pine	2,608,674	2,020,337	398,010	20,703	4,395	165,229	46
White pine	653,714	345,377	71,619	18,568	4,704	213,446	45
White spruce	102,932	10,263	4,399	-	-	88,270	45
Black spruce	36,938	25,494	11,444	-	-	-	45
Balsam fir	7,894	5,718	2,176	-	-	-	47
Hemlock	-	-	-	-	-	-	-
Tamarack	-	-	-	-	-	-	-
Eastern redcedar	225,646	52,559	24,428	49,036	20,270	79,353	43
Northern white-cedar	-	-	-	-	-	-	-
Other softwoods	-	-	-	-	-	-	-
Total	3,886,673	2,609,161	539,544	135,372	37,643	564,953	46
Hardwoods							
Select white oak	20,465,920	10,175,061	4,052,791	4,001,431	1,543,137	693,500	58
Select red oak	25,453,114	15,653,599	5,518,101	3,013,283	1,017,924	250,207	64
Other red oak	13,577,213	6,476,474	2,428,475	3,295,044	1,199,801	177,419	64
Select hickory	5,356,349	2,963,606	1,253,912	548,463	232,130	358,238	63
Other hickory	2,586,713	1,342,484	625,107	114,296	50,381	454,445	59
Basswood	6,179,662	3,174,946	1,218,313	976,045	339,532	470,826	42
Beech	-	-	-	-	-	-	-
Yellow birch	68,410	48,850	19,560	-	-	-	61
Hard maple	8,900,017	4,577,838	1,662,867	1,633,065	537,770	488,477	63
Soft maple	6,302,097	3,329,005	1,241,337	863,720	295,704	572,331	55
Elm	6,337,023	2,842,855	1,201,337	1,101,697	440,737	750,397	55
Black ash	833,017	421,279	180,862	75,252	31,724	123,900	50
White & green ash	2,737,721	1,534,842	613,620	250,937	91,383	246,939	51
Cottonwood	909,482	643,660	213,267	36,620	9,503	6,432	51
Willow	551,261	248,718	98,630	119,911	38,256	45,746	48
Hackberry	96,027	46,241	22,580	5,152	2,635	19,419	52
Balsam poplar	62,285	44,416	13,950	-	-	3,919	53
Bigtooth aspen	4,412,123	3,073,815	887,223	200,487	53,344	197,254	50
Quaking aspen	4,313,340	2,502,462	805,597	453,222	148,578	403,481	50
Paper birch	5,978,263	3,216,277	1,378,170	578,673	228,983	576,160	55
River birch	498,798	240,912	94,913	65,679	21,576	75,718	55
Black cherry	3,298,586	1,456,687	622,848	562,274	238,002	418,775	49
Black walnut	1,007,539	582,581	224,969	143,065	54,684	2,240	54
Butternut	1,702,810	696,321	277,609	472,560	187,141	69,179	45
Other nardwoods	1,571,768	298,129	131,475	492,526	205,726	443,912	46
Noncommercial spp.	2,909,050	-	-	635,396	336,913	1,936,741	50
Total	126,108,588	65,591,058	24,787,513	19,638,798	7,305,564	8,785,655	57
All species	129,995,261	68,200,219	25,327,057	19,774,170	7,343,207	9,350,608	56

(Table 19 continued on next page)

(Table 19 continued)

SOUTHEAST

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops, limbs, and stumps	Bole	Tops, limbs, and stumps		
	- - - -	- - - -	- - - -	Green tons	- - - -	- - - -	- Pounds -
Softwoods							
Jack pine	76,770	62,521	14,249	-	-	-	46
Red pine	842,799	678,206	131,571	14,066	2,686	16,270	46
White pine	950,188	551,941	113,340	20,858	4,369	259,680	45
White spruce	226,836	141,190	55,859	-	-	29,787	45
Black spruce	102,831	26,037	12,038	-	-	64,756	45
Balsam fir	232,518	69,914	30,472	3,169	1,735	127,228	47
Hemlock	119,473	79,620	33,423	2,631	1,316	2,483	51
Tamarack	507,081	349,353	68,897	5,300	1,059	82,472	52
Eastern redcedar	160,456	32,417	14,838	13,820	6,701	92,680	43
Northern white-cedar	3,258,823	1,691,541	731,588	183,534	76,524	575,636	36
Other softwoods	22,961	15,996	6,965	-	-	-	44
Total	6,500,736	3,698,736	1,213,240	243,378	94,390	1,250,992	41
Hardwoods							
Select white oak	6,920,506	4,031,046	1,456,668	968,556	351,488	112,748	58
Select red oak	4,909,848	3,058,571	1,031,526	515,113	167,216	137,422	64
Other red oak	3,567,818	1,970,758	741,267	577,671	207,391	70,731	64
Select hickory	2,425,098	1,398,044	569,147	234,906	93,579	129,422	63
Other hickory	508,810	271,940	123,992	23,744	9,434	79,700	59
Basswood	1,456,609	776,027	286,424	191,300	64,637	138,221	42
Beech	1,046,433	470,899	177,466	235,297	85,947	76,824	59
Yellow birch	514,490	273,639	122,194	80,894	31,077	6,686	61
Hard maple	4,472,855	2,560,380	940,592	535,630	170,532	265,721	63
Soft maple	3,695,630	1,885,977	695,866	587,854	194,389	331,544	55
Elm	2,756,110	1,248,000	519,398	393,009	160,512	435,191	55
Black ash	2,112,439	1,171,639	543,038	71,381	31,398	294,983	50
White & green ash	4,628,203	2,562,606	1,009,808	365,746	139,074	550,969	51
Cottonwood	279,167	161,822	52,183	45,552	19,610	-	51
Willow	879,613	364,672	132,399	259,675	91,266	31,601	48
Hackberry	35,100	25,585	9,046	-	-	469	52
Balsam poplar	220,924	124,865	40,965	30,851	8,536	15,707	53
Bigtooth aspen	834,672	625,736	175,017	22,404	6,660	4,855	50
Quaking aspen	2,646,173	1,423,114	478,453	262,040	82,265	400,301	50
Paper birch	1,382,067	767,302	327,625	35,924	14,992	236,224	55
River birch	-	-	-	-	-	-	-
Black cherry	2,659,605	1,207,638	483,665	419,707	161,396	387,199	49
Black walnut	345,457	206,719	82,347	33,618	14,351	8,422	53
Butternut	142,319	80,512	34,247	15,898	6,193	5,469	45
Other hardwoods	1,132,853	254,526	116,067	361,911	157,012	243,337	46
Noncommercial spp.	1,288,841	-	-	425,001	216,867	646,973	50
Total	50,861,640	26,922,017	10,149,400	6,693,682	2,485,822	4,610,719	55
All species	57,362,376	30,620,753	11,362,640	6,937,060	2,580,212	5,861,711	53

Smith, W. Brad; Hahn, Jerold T.
1989. **Wisconsin's forest statistics, 1987: an inventory update.** Gen. Tech. Rep. NC-130. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

The Wisconsin 1987 inventory update, derived by using tree growth models, reports 14.7 million acres of timberland, a decline of less than 1 percent since 1983. This bulletin presents findings from the inventory update in tables detailing timberland area, volume, and biomass.

KEY WORDS: Forest area, timberland, forest inventory, land use, update.

FINDING OUT AND TELLING

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it--in short, "finding out and telling." As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

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Forest Service

North Central Forest Experiment Station

General Technical Report **NC-131**

Empirical Yield Tables for Wisconsin

Jerold T. Hahn and Joan M. Stelman

White pine
Red pine
Jack pine
White spruce
Black spruce
Balsam fir
Hemlock
Tamarack
Northern white-cedar
White oak
Red oak
Hickory
Yellow birch
Hard maple
Soft maple
Beech
Ash
Balsam poplar
Cottonwood
Bigtooth aspen
Quaking aspen
Basswood
Yellow-poplar
Black walnut
Black cherry
Butternut
Elm
Paper birch

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Empirical Yield Tables for Wisconsin

Jerold T. Hahn and Joan M. Stelman

Empirical yield tables are useful to managers of timber, wildlife, and other forest resources who are interested in estimating current commercial forest species composition and volume or in making rough, short-term (20-30 years) projections of future conditions. This paper provides empirical yield tables for Wisconsin and demonstrates some uses for them. If you are interested in comparing conditions in the Lake States, similar sets of tables are presented in "Empirical yield tables for Michigan" (Hahn and Stelman 1984) and "Empirical yield tables for Minnesota" (Hahn and Raile 1982). In addition, unpublished empirical yield tables for Missouri (1972) and Iowa (1974) are available at cost from the Forest Inventory and Analysis Research Work Unit at the North Central Forest Experiment Station.

We compiled yield tables for Wisconsin from data gathered on 6,999 timberland plots established during the 1983 inventory of Wisconsin's five Forest Survey Units (fig.1)[1]. The tables give the estimated merchantable cubic foot volume yield per acre from growing-stock trees and the average basal area per acre of all live trees 1 inch diameter breast height (d.b.h.) and larger by stand-age class for the 14 forest types defined in the Appendix. In addition to the net cubic foot volume tables, we present tables showing data generated from a 30-year projection of the base year data and total green weight of above-ground biomass for all live trees. These tables provide a detailed picture of stand composition as measured by growing-stock volume or above-ground biomass.

We constructed the tables by classifying the timberland plots by forest type, stand-age class, and site-index class. Then the per acre merchantable cubic foot volume or the total above-ground biomass was tabulated by species group. The merchantable volume standards used are minimum 5-inch d.b.h. to a 4-inch top diameter outside bark (top d.o.b.) with a 1-foot stump. We computed individual tree volumes using a formula developed from "Composite volume tables for timber and their application in the Lake States" (Gevorkiantz and Olsen 1955) as described by Hahn (1984) and Smith (1985).

The 30-year projections were made using the STEMS growth projection system (Belcher *et al.* 1982) without management, following methods described in Ek *et al.* (1985, 1987). The 30-year projection provided additional plot volumes at three 10-year intervals. Therefore, in the projection tables, an average 75 percent of the data in a stand-age class is from projected data. This procedure allowed us to smooth out some of the abrupt changes in volumes common to empirical yield tables and to provide estimates for age classes not represented in the initial sample.

In this report, we present tables by forest type and site-index class for the entire State and for each Forest Survey Unit. State total tables for all sites are printed. State total tables by site-index class and Survey Unit tables are included as microfiche inside the back cover. We have included only tables having sufficient data, usually 3 or 4 plots, in each of three adjacent age classes. We feel that information based on smaller samples would not be useful.

Jerold T. Hahn is a Principal Mensurationist and **Joan A. Stelman** is a Statistical Assistant with the North Central Forest Experiment Station, St. Paul, MN.

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[1] *A full explanation of the survey procedures and definitions can be obtained from "Wisconsin's fourth forest inventory, 1983" (Spencer* et al. *1988).*

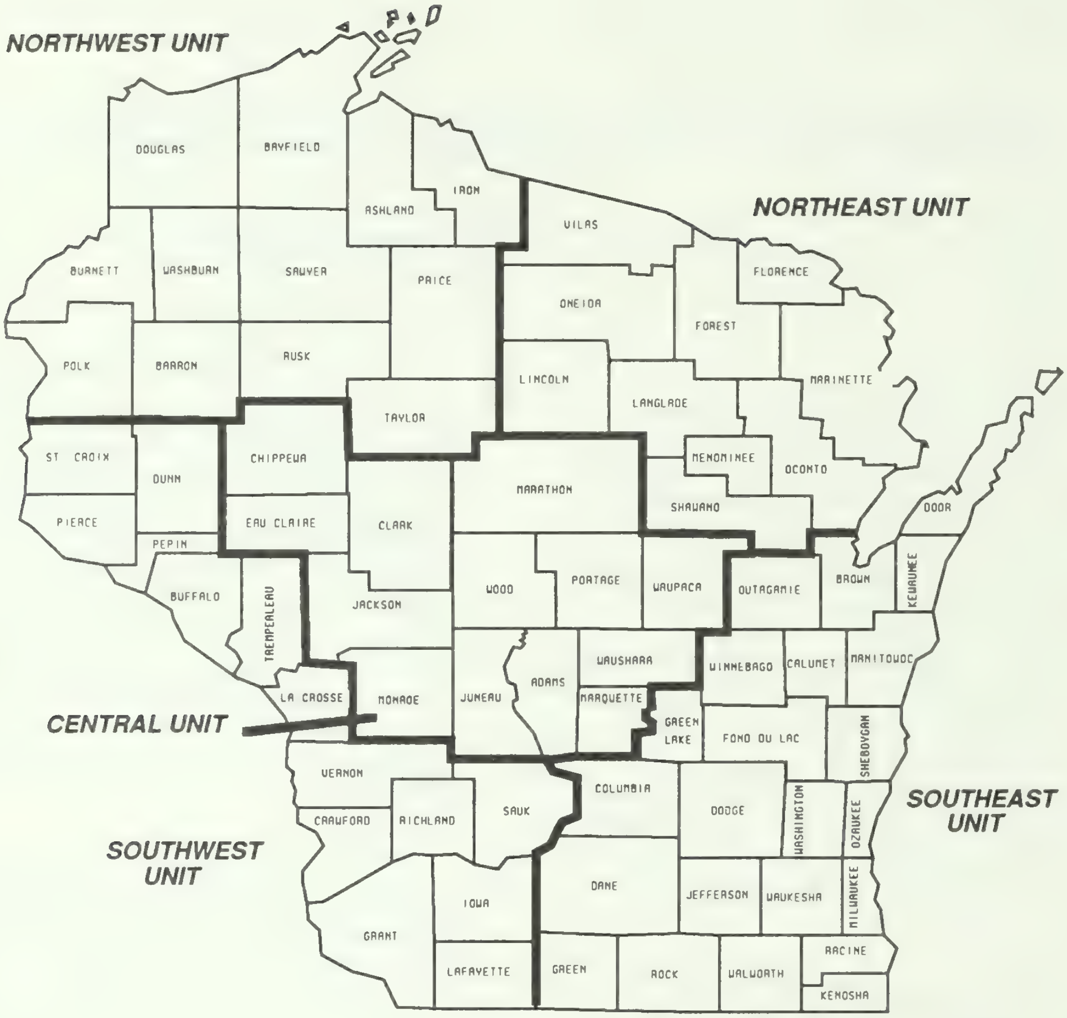

Figure 1.--*Wisconsin's Forest Survey Units.*

The tables can be used in several ways. For example, they can be used to estimate future timber yield in the same manner as normal yield tables—it is assumed that the volume shown in one age class will increase in 10 years to the volume shown in the next older age class. For example, red pine stands aged 61-70 years currently average 1,904 cubic feet per acre (table 2). If you have a stand of red pine 51-60 years old, you could expect that in 10 years the stand would yield approximately 1,904 cubic feet per acre. If users understand and accept the assumptions and accuracy of the growth processor, the same analysis can be made using table 15 (for all sites of red pine) where the expected yield would be 4,030 cubic feet per acre. However, we caution users that it would be much better to use the projection tables by site-index class from the microfiche.

Rotation age (Years)	Area harvested/ year[2]		Merchantable volume/ acre[3]		Annual harvest volume
	Thousand acres		*Cubic feet*		*Million cubic feet*
35	93.2	X	1,042	=	97.1
45	72.5	X	1,256	=	91.1
55	59.3	X	1,381	=	81.9

As a second example, these tables can be used in conjunction with other published forest inventory data to compare volume estimates for progressive rotation ages. For instance, the aspen type occupied 3,261,500 acres in Wisconsin in 1983 (Spencer *et al.* 1988). Assuming that you would harvest an equal number of acres each year, estimates of the annual harvest volume can be derived using the yields shown in table 12.

These harvest volumes can also be broken down by species group. (See Appendix for a detailed breakdown of the species groups.) By using table 12, the annual harvest volume is further broken down into softwoods and hardwoods.

According to this analysis, the greatest total yield and the greatest softwood yield would be attained by using a 35-year rotation for the aspen type. However, more acres would have to be harvested each year to obtain that volume. Currently, more than 40 percent of the plots in the aspen type are in stands older than 35 years. Therefore, considerable volume from older plots would have to be harvested to reach a 35-year rotation.

Rotation age (Years)	Harvest volume		
	Total	Softwoods	Hardwoods
	- - - - - *Million cubic feet* - - - - -		
35	97.1	9.5[4]	87.6
45	91.1	7.1	84.0
55	81.9	9.2	72.7

Finally, tables by basal area allow a comparison between stand density and stand age that can be used with other inventory data to determine the stocking of existing stands. For example, in 1983 there were 404.9 thousand acres of aspen 51-60 years old in Wisconsin (Spencer *et al.* 1988). Yields in these stands (all species) averaged 97 square feet per acre (table 12). Thus, the ratio of volume to basal area was 14.2 to 1. Schlaegel (1971) predicted that such a ratio for fully stocked stands of aspen in Minnesota would be 26 to 1. If we view Schlaegel's prediction as an index of stand potential, we can estimate that fully stocked aspen sites should yield roughly twice what the stands in the example are producing now. The comparison is approximate because Schlaegel used different standards of merchantability in computing his volume.

The volumes shown in these tables were obtained from plots located in stands with various histories, from undisturbed stands to those that had been repeatedly cut. Thus, the standard errors of mean volume given in the tables indicate their variation. Sampling error in percent can be determined by dividing the standard error by the mean volume of all species. For example, the sampling error for jack pine in the 41-50 year age class for all sites combined (table 1) is 33.5 percent (410/1,225) X 100.

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[2] *Total type acreage (3,261,500 acres)/rotation age (35 years).*

[3] *From table 12.*

[4] *Cubic feet/acre of softwoods or hardwoods in the forest type of interest (102 cubic feet) X number of acres in the forest type (93,200 acres).*

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APPENDIX

Definition of Terms

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal areas of all live trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Biomass.—The total above-ground weight, excluding foliage, of all live trees reported in green tons. Biomass is made up of 5 components:

Growing-stock stumps.—Biomass of a growing-stock tree 1-foot stump.

Growing-stock bole.—Biomass of a growing-stock tree from a 1-foot stump to a variable 4-inch top.

Growing-stock top and limbs.—Biomass of a growing-stock tree from a 1-foot stump minus the growing-stock bole.

Cull stumps.—Biomass of a cull tree 1-foot stump.

Cull bole.—Biomass of a cull tree from a 1-foot stump to a variable 4-inch top.

Cull top and limbs.—Biomass of a cull tree from a 1-foot stump minus the cull bole.

1- to 5-inch trees.—Above-ground biomass of all live trees 1- to 5-inches in diameter at breast height.

Forest type.—A classification of forest land based upon the species forming a plurality of live tree stocking. Major forest types in Wisconsin are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and oak.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and oak.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include balsam fir, tamarack, and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include balsam fir, tamarack, and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce, balsam fir, and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, elm, and maple.)

Elm-ash-soft maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birch, aspen, and balsam fir.)

Maple-birch.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include oak, pines, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprise a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Exotic.—Forests in which species not native to Wisconsin comprise a plurality of the stocking. (Mostly Scotch pine plantations.)

Growing-stock trees.—Live trees of commercial species that meet specified standards of size, quality, and merchantability. (Note: Excludes rough and rotten trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to cords by dividing by 79 cubic feet per solid wood cord (rough standard cord excluding bark and air spaces).

Live trees.—Growing-stock, rough, and rotten trees 1-inch d.b.h. and larger.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Site index.—An expression of forest site quality based on the height of a free-growing dominant or codominant tree of a representative species in the forest type at age 50.

Stand age.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stocking.—The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard.

A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h.

Stands are grouped into the following stocking classes:

Overstocked stands.—Stands in which stocking of trees is 130.0 percent or more.

Fully stocked stands.—Stands in which stocking of trees is from 100.0 to 129.9 percent.

Medium stocked stands.—Stands in which stocking of trees is from 60.0 to 99.9 percent.

Poorly stocked stands.—Stands in which stocking of trees is from 16.7 to 59.9 percent.

Nonstocked areas.—Timberland on which stocking of trees is less than 16.7 percent.

Timberland.—(This is a new term universally used in Forest Inventory and Analysis reports and is exactly equivalent to the term "commercial forest land" previously used.) Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as timberland have the capability of producing in excess of 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)

Tree Species Groups in Wisconsin[5]

SOFTWOODS	
Jack pine	*Pinus banksiana*
Red pine	*Pinus resinosa*
Eastern white pine	*Pinus strobus*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea*
Eastern hemlock	*Tsuga canadensis*
Tamarack	*Larix laricina*
Eastern redcedar	*Juniperus virginiana*
Northern white-cedar	*Thuja occidentalis*
Other softwoods	
Norway spruce	*Picea abies*
Scotch pine	*Pinus sylvestris*
HARDWOODS	
White oak	
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Bur oak	*Quercus macrocarpa*
Select red oak	
Northern red oak	*Quercus rubra*
Other red oak	
Northern pin oak	*Quercus ellipsoidalis*
Black oak	*Quercus velutina*
Select hickory	
Shagbark hickory	*Carya ovata*
Other hickory	
Pignut hickory	*Carya glabra*
Bitternut hickory	*Carya cordiformis*
American basswood	*Tilia americana*
Beech	*Fagus grandifolia*
Yellow birch	*Betula alleghaniensis*
Hard maple	
Sugar maple	*Acer saccharum*
Black maple	*Acer nigrum*
Soft maple	
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Elm	
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*
Rock elm	*Ulmus thomasii*
Black ash	*Fraxinus nigra*
White and green ash	
White ash	*Fraxinus americana*
Green ash	*Fraxinus pennsylvanica*
Eastern cottonwood	*Populus deltoides*
Black willow	*Salix nigra*
Hackberry	*Celtis occidentalis*
Balsam poplar	*Populus balsamifera*
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Paper birch	*Betula papyrifera*
River birch	*Betula nigra*
Black cherry	*Prunus serotina*
Black walnut	*Juglans nigra*
Butternut	*Juglans cinerea*
Other hardwoods	
Boxelder	*Acer negundo*
Black locust	*Robinia pseudoacacia*
Honeylocust	*Gleditsia triacanthos*
Red mulberry	*Morus rubra*
Northern catalpa	*Catalpa speciosa*
Noncommercial species	
Mountain maple	*Acer spicatum*
Eastern hophornbeam	*Ostrya virginiana*
Peachleaf willow	*Salix amygdaloides*
American hornbeam	*Carpinus caroliniana*
Hawthorn	*Crataegus* spp.
Striped maple	*Acer pensylvanicum*
Mountain-ash	*Sorbus* spp.
Pin cherry	*Prunus pensylvanica*
Chokecherry	*Prunus virginiana*

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[5] *The common and scientific names are based on: Little, Elbert L. 1979.Checklist of United States trees (native and naturalized). Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service. 375 p.*

Table 1.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Jack pine   All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	15	0	2	1	10	8	70	20	85	152	0	0	0
Red pine	47	23	17	27	22	62	59	300	293	498	0	0	0
Jack pine	658	133	230	502	862	860	1,002	658	1,091	772	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	2	0	0	0	3	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	44	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	19	0	0	0	0
Total softwoods	720	156	251	530	894	930	1,134	978	1,488	1,466	0	0	0
Hardwoods													
Select white oak	1	2	0	1	3	3	0	0	0	0	0	0	0
Select red oak	7	0	1	0	17	10	0	0	40	63	0	0	0
Other red oak	24	3	8	12	15	57	24	15	97	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	1	0	2	1	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	1	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	6	2	12	0	0	6	21	0	0	0	0	0	0
Quaking aspen	35	3	2	13	78	38	46	47	22	78	0	0	0
Basswood	0	0	0	0	0	1	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	2	0	0	0	0	0	0	0	0
Paper birch	4	0	1	3	3	7	0	0	53	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	77	10	26	29	120	123	91	62	212	141	0	0	0
Total all species	797	166	277	559	1,014	1,053	1,225	1,040	1,700	1,607	0	0	0
Number of plots	261	19	47	38	59	59	28	5	5	1	0	0	0
Standard error	140	94	174	235	345	423	410	672	1,368	3/	0	0	0
Average basal area	71	22	48	67	84	84	85	69	110	80	0	0	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 2.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Red pine   All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	93	2	17	29	55	221	216	123	604	487	376	638	0
Red pine	1,242	66	578	1,764	1,790	1,599	1,496	1,212	1,290	1,651	1,302	1,175	0
Jack pine	55	2	7	65	90	123	114	100	76	0	46	0	0
White spruce	7	6	0	5	1	0	0	28	0	92	46	129	0
Black spruce	4	0	0	7	0	0	13	57	35	0	0	39	0
Balsam fir	9	0	0	1	12	0	0	141	25	28	77	68	0
Hemlock	2	0	0	0	0	0	0	0	43	0	63	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	1	0	0	0	0	0	0	0	0	61	21	0	0
Other softwoods	3	0	7	1	0	0	32	0	0	0	0	0	0
Total softwoods	1,416	76	609	1,872	1,948	1,943	1,871	1,661	2,073	2,319	1,931	2,049	0
Hardwoods													
Select white oak	0	0	2	1	0	0	0	0	0	0	0	0	0
Select red oak	14	2	6	0	9	0	146	0	36	94	29	37	0
Other red oak	13	0	27	20	10	0	9	0	0	0	12	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	12	0	0
Hard maple	6	0	7	0	15	3	0	0	35	31	10	28	0
Soft maple	9	0	3	0	2	51	0	0	42	66	20	171	0
Beech	0	0	3	0	0	0	0	0	0	0	0	0	0
Ash	1	0	5	0	0	4	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	8	0	1	3	16	0	0	59	58	45	24	43	0
Quaking aspen	42	0	27	10	101	59	0	131	205	70	23	36	0
Basswood	0	0	1	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	3	0	1	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	6	0	0	0	0	8	0	0
Paper birch	13	14	4	3	6	0	48	53	0	101	58	205	0
Other hardwoods	1	0	1	0	4	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	107	19	87	38	163	123	203	243	376	407	196	520	0
Total all species	1,523	95	696	1,910	2,111	2,066	2,074	1,904	2,449	2,726	2,127	2,569	0
Number of plots	211	24	47	51	40	17	11	4	5	4	6	2	0
Standard error	289	76	275	830	843	1,201	947	1,461	1,624	2,451	971	3/	0
Average basal area	100	9	65	127	130	127	124	116	138	145	115	128	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 3.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - White pine All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	939	208	380	456	460	968	608	888	1,399	1,096	758	1,283	2,014
Red pine	183	73	146	220	236	258	168	292	250	110	143	201	85
Jack pine	52	0	0	58	61	81	105	120	58	26	0	67	0
White spruce	20	12	0	23	0	0	0	14	101	24	0	16	0
Black spruce	17	0	0	65	0	19	31	0	23	31	0	0	15
Balsam fir	33	0	0	0	0	0	8	11	86	84	0	16	81
Hemlock	13	0	0	0	0	28	0	0	23	5	0	19	57
Tamarack	5	0	0	0	0	0	29	0	0	11	0	0	6
Northern white-cedar	9	0	0	0	0	0	0	0	0	4	0	13	87
Other softwoods	1	0	0	0	0	0	11	0	0	0	0	0	0
Total softwoods	1,272	293	526	822	757	1,354	960	1,325	1,940	1,391	901	1,615	2,345
Hardwoods													
Select white oak	13	0	0	0	5	17	25	14	16	18	0	13	19
Select red oak	15	0	0	0	0	0	7	22	27	5	78	0	66
Other red oak	27	0	0	0	10	28	14	110	32	26	0	106	0
Hickory	1	0	0	0	16	0	0	0	0	0	0	0	0
Yellow birch	1	0	20	0	0	0	0	0	0	0	0	0	0
Hard maple	7	0	20	0	0	0	0	0	0	0	0	95	17
Soft maple	49	0	8	0	7	5	27	84	74	44	82	119	147
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	5	0	0	0	0	0	0	0	4	10	0	72	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	22	0	0	399	0	0	0	0	8	0	0	0	0
Bigtooth aspen	16	0	0	19	0	9	16	8	82	9	0	0	0
Quaking aspen	118	22	63	91	159	146	153	151	131	156	0	169	48
Basswood	4	0	0	0	0	0	12	0	0	5	0	0	20
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	4	0	18	0	8	0	0	0	0	0	0	63	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	7	0	0	9	6	0	0	2	0	0	0
Paper birch	44	0	0	0	23	59	44	0	94	68	0	45	88
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	328	22	136	509	228	273	304	389	468	343	160	682	405
Total all species	1,600	315	662	1,331	985	1,627	1,264	1,714	2,408	1,734	1,061	2,297	2,750
Number of plots	113	9	8	6	9	11	12	10	15	15	2	5	11
Standard error	282	179	335	802	530	716	552	896	1,393	689	3/	1,586	1,430
Average basal area	100	28	86	96	83	110	100	117	121	106	73	120	124

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 4.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Black spruce   All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	15	0	6	10	18	16	4	0	102	44	51	0	0
Red pine	16	8	20	12	14	4	29	0	89	0	0	0	0
Jack pine	1	0	0	0	0	0	15	0	0	16	0	0	0
White spruce	3	0	0	1	0	3	0	0	48	0	0	0	0
Black spruce	200	59	74	61	152	365	253	524	444	988	240	0	88
Balsam fir	31	17	9	11	12	40	69	74	147	55	63	0	0
Hemlock	9	0	6	0	0	0	0	0	38	81	254	0	0
Tamarack	48	44	38	34	27	32	124	101	53	129	0	0	127
Northern white-cedar	16	0	20	0	0	27	14	34	66	22	199	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	339	128	173	129	223	487	508	733	987	1,335	807	0	215
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	4	0	2	9	0	11	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	7	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	2	0	0	8	0	8	0	0	0	0
Hard maple	0	0	0	1	0	0	0	0	8	0	0	0	0
Soft maple	7	0	2	4	0	14	28	8	34	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	14	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	4	0	0	12	2	0	0	0	8	0	0	0	0
Quaking aspen	43	41	25	45	33	70	103	17	59	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	40	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	15	0	11	15	19	30	17	20	29	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	74	41	40	88	54	125	156	59	153	0	40	0	0
Total all species	413	169	213	217	277	612	664	792	1,140	1,335	847	0	215
Number of plots	142	16	23	38	18	16	8	8	7	5	2	0	1
Standard error	84	115	128	147	186	318	399	474	781	907	3/	0	3/
Average basal area	60	30	46	48	65	86	76	69	106	120	63	0	15

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 5.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Balsam fir All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	31	26	5	10	9	32	39	8	58	13	158	350	50
Red pine	9	5	13	3	0	7	11	3	0	50	53	29	0
Jack pine	1	9	0	0	0	0	0	0	0	0	0	0	0
White spruce	65	14	25	38	93	80	93	41	145	115	74	178	0
Black spruce	42	29	18	6	54	49	46	53	151	0	0	132	0
Balsam fir	445	100	153	220	457	551	681	646	476	541	488	391	192
Hemlock	16	8	0	7	23	9	12	10	32	36	0	0	337
Tamarack	12	3	8	13	0	5	16	15	0	7	0	160	0
Northern white-cedar	91	36	78	60	142	88	78	109	118	186	0	98	506
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	712	230	300	357	778	821	976	885	980	948	773	1,338	1,085
Hardwoods													
Select white oak	0	1	0	0	2	0	0	0	0	0	0	0	0
Select red oak	1	2	4	0	0	4	1	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	6	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	12	1	4	5	0	27	7	20	9	60	0	17	45
Hard maple	6	6	0	13	0	14	9	0	0	7	0	0	0
Soft maple	30	13	16	33	8	37	41	7	43	130	72	36	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	24	24	8	12	13	39	9	70	8	43	0	0	0
Balsam poplar	3	0	0	0	4	0	14	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	3	4	25	0	0	4	2	0	0	0	0	0	15
Quaking aspen	89	23	87	58	65	220	99	71	47	53	89	217	0
Basswood	0	0	0	2	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	5	0	0	0	0	9	20	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	5	0	0	1	5	11	7	12	0	0	0	0	0
Paper birch	50	23	39	33	55	54	63	71	104	35	0	40	16
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	228	97	183	157	152	419	272	251	211	334	161	310	76
Total all species	940	327	483	514	930	1,240	1,248	1,136	1,191	1,282	934	1,648	1,161
Number of plots	213	29	16	24	16	27	49	27	8	8	2	4	3
Standard error	152	157	241	191	400	477	478	503	863	568	3/	936	847
Average basal area	85	33	60	61	93	111	105	94	105	105	68	107	115

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 6.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, All Units, Wisconsin, 1983[1]

Forest type - Northern white-cedar   All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	27	19	0	0	26	15	20	9	12	12	52	6	83
Red pine	0	0	0	0	0	4	0	0	0	0	0	5	0
Jack pine	1	0	0	0	0	0	0	0	14	0	0	0	0
White spruce	18	0	10	8	0	11	41	29	12	17	11	29	19
Black spruce	45	41	0	28	33	34	41	69	26	65	36	3	91
Balsam fir	109	8	33	33	44	119	120	157	138	87	87	111	147
Hemlock	33	11	0	0	0	3	24	7	5	16	51	16	135
Tamarack	40	0	10	43	17	104	79	48	33	0	49	10	10
Northern white-cedar	789	169	322	289	330	607	806	913	788	651	925	1,191	1,068
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	1,062	248	375	401	450	897	1,131	1,232	1,028	848	1,211	1,371	1,553
Hardwoods													
Select white oak	0	14	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	0	0	6	0	0	0	0	4	0	0	0	0
Other red oak	0	0	0	5	0	0	0	0	4	0	0	0	0
Hickory	1	15	0	0	0	4	0	0	0	0	0	4	0
Yellow birch	26	0	0	0	0	0	29	22	16	23	34	29	76
Hard maple	0	0	0	0	0	0	0	0	0	0	0	4	0
Soft maple	23	0	64	16	72	3	43	22	17	20	26	24	20
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	46	0	0	12	20	11	23	49	81	31	53	86	86
Balsam poplar	3	0	0	0	0	2	0	4	0	0	16	6	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	4	0	0	0	0	0	35	7	0	0	0	0	0
Quaking aspen	31	13	53	0	47	67	50	56	27	21	10	34	4
Basswood	2	12	0	0	0	0	0	0	0	0	15	4	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	6	0	8	0	0	4	8	27	0	5	5	3	2
Paper birch	52	16	54	40	92	61	75	80	42	40	34	75	27
Other hardwoods	0	0	0	0	22	0	0	0	0	0	0	0	2
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	194	70	179	79	253	152	263	267	191	140	193	269	217
Total all species	1,256	318	554	480	703	1,049	1,394	1,499	1,219	988	1,404	1,640	1,770
Number of plots	171	4	7	10	4	20	16	19	15	15	22	14	25
Standard error	320	295	328	292	639	536	706	1,047	1,055	698	1,152	1,395	1,323
Average basal area	130	39	80	92	74	120	123	153	131	116	154	141	158

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 7.--Cubic foot volume per acre in growing-stock trees by species 1/ group and stand-age class, All Units, Wisconsin, 1983

Forest type - Tamarack   All sites

(In cubic feet per acre)

Species group	Average 2/	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	26	28	13	9	4	22	19	33	93	31	0	193	0
Red pine	2	0	0	3	0	0	0	9	10	0	0	0	0
Jack pine	1	0	0	2	0	14	0	0	0	0	0	0	0
White spruce	4	7	0	0	0	9	4	8	0	0	0	0	103
Black spruce	34	25	16	32	13	71	73	39	25	33	0	167	0
Balsam fir	24	1	21	16	22	90	9	18	40	49	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	5	0	0	0
Tamarack	321	174	100	127	492	418	578	689	619	465	0	484	544
Northern white-cedar	7	0	0	0	0	6	18	12	29	32	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	419	235	150	189	531	630	701	808	816	615	0	844	647
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	4	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	2	0	0	0	0	0	4	0	0	0	0
Hard maple	0	0	2	0	0	0	0	0	0	0	0	0	0
Soft maple	15	7	5	22	17	7	35	20	45	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1	0	0	0	0	0	0	22	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	9	17	0	0	0	84	9	0	0	0	0	0	0
Quaking aspen	20	0	19	8	8	127	0	41	15	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	5	15	0	0	0	7	0	0	0
Paper birch	22	36	14	3	28	33	24	59	27	8	0	37	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	68	64	42	33	58	266	68	142	91	15	0	37	0
Total all species	487	299	192	222	589	896	769	950	907	630	0	881	647
Number of plots	119	16	26	22	7	9	9	10	8	8	0	2	2
Standard error	86	141	90	141	320	503	484	460	510	381	0	3/	3/
Average basal area	50	29	28	45	72	70	65	68	79	57	0	71	43

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 8.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - White spruce All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	45	0	57	0	16	0	0	745	0	0	0	0	0
Red pine	12	0	21	16	26	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	1,064	0	282	1,606	2,370	1,150	1,375	1,498	0	0	0	0	0
Black spruce	5	0	0	0	30	0	0	0	0	0	0	0	0
Balsam fir	56	0	12	0	75	150	108	348	0	0	0	0	0
Hemlock	2	0	12	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	16	0	0	0	86	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	1,200	0	384	1,622	2,603	1,300	1,483	2,591	0	0	0	0	0
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	4	0	19	0	0	0	0	0	0	0	0	0	0
Hard maple	11	0	26	0	13	20	0	0	0	0	0	0	0
Soft maple	16	0	0	0	87	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	19	0	0	0	27	94	0	87	0	0	0	0	0
Balsam poplar	6	0	0	0	0	0	87	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	30	0	0	0	0	0	0	0
Quaking aspen	66	40	68	0	0	200	205	89	0	0	0	0	0
Basswood	2	0	0	0	0	21	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	2	0	10	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	3	0	15	0	0	0	0	0	0	0	0	0	0
Paper birch	9	0	0	0	0	0	0	258	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	141	40	138	0	127	365	292	434	0	0	0	0	0
Total all species	1,341	40	522	1,622	2,730	1,665	1,775	3,025	0	0	0	0	0
Number of plots	26	5	6	4	5	3	2	1	0	0	0	0	0
Standard error	531	45	307	1,790	2,382	1,187	3/	3/	0	0	0	0	0
Average basal area	99	7	68	122	168	128	132	152	0	0	0	0	0

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

[3/] Insufficient number of plots to compute the standard error.

Table 9.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, All Units, Wisconsin, 1983

Forest type - Oak-hickory All sites

(In cubic feet per acre)

Species group	Average 2/	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	18	10	5	6	10	7	17	16	50	22	23	6	38
Red pine	9	6	12	4	26	6	7	13	4	35	2	0	0
Jack pine	29	40	33	41	82	39	38	35	15	10	14	4	3
White spruce	0	0	0	4	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	6	0	0	2	0	0	0	0	0
Hemlock	0	0	0	2	1	0	0	0	3	0	0	0	0
Tamarack	0	0	0	0	1	0	0	1	0	1	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	1	0	1	0	0	0	0	4	0	0	0
Total softwoods	56	56	51	57	127	52	62	67	72	72	39	10	41
Hardwoods													
Select white oak	160	27	44	77	106	109	122	174	168	287	288	276	321
Select red oak	318	38	66	96	137	318	464	282	456	438	360	529	370
Other red oak	181	81	67	107	222	260	219	272	209	197	153	132	139
Hickory	40	14	13	36	60	52	31	44	40	56	54	56	43
Yellow birch	0	0	0	0	0	0	0	1	2	0	0	0	0
Hard maple	17	2	0	2	11	6	9	16	38	20	34	54	18
Soft maple	39	3	1	8	27	51	62	35	74	35	33	43	40
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	12	0	5	1	7	7	16	11	21	24	14	20	12
Balsam poplar	0	0	0	0	0	0	3	0	0	0	0	0	0
Cottonwood	2	0	2	2	1	2	2	3	0	5	0	1	0
Bigtooth aspen	51	12	7	19	48	74	93	65	73	51	31	35	30
Quaking aspen	31	12	6	45	27	65	63	29	22	16	19	13	13
Basswood	24	2	2	8	11	18	25	19	27	55	26	48	41
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	5	6	0	3	0	1	4	4	6	7	7	4	12
Black cherry	19	3	4	16	28	31	18	14	26	33	9	25	19
Butternut	5	4	0	0	14	9	6	5	0	0	3	11	2
Elm	15	9	2	7	10	13	9	19	17	29	31	24	17
Paper birch	38	7	10	33	60	48	76	69	34	15	38	22	20
Other hardwoods	1	0	1	0	0	0	4	1	0	6	0	2	3
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	958	220	230	460	769	1,064	1,226	1,063	1,213	1,274	1,100	1,295	1,100
Total all species	1,014	276	281	517	896	1,116	1,288	1,130	1,285	1,346	1,139	1,305	1,141
Number of plots	1,199	148	65	41	53	142	177	116	117	90	64	98	88
Standard error	108	116	120	179	308	368	413	344	376	429	366	412	395
Average basal area	85	38	45	63	82	95	100	100	100	98	89	95	95

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 10.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Elm-ash-soft maple All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	18	1	4	11	10	23	24	36	17	38	7	13	30
Red pine	0	1	0	0	0	0	2	0	1	0	0	0	0
Jack pine	1	0	0	0	5	4	2	0	0	0	0	0	0
White spruce	6	1	4	1	9	7	3	13	8	10	9	3	7
Black spruce	2	0	0	1	2	2	6	3	0	1	0	8	3
Balsam fir	45	6	8	30	38	69	52	77	65	33	36	66	68
Hemlock	14	0	4	5	0	5	9	26	22	21	23	68	51
Tamarack	8	3	3	6	17	6	7	15	20	5	0	0	0
Northern white-cedar	40	15	13	18	23	34	15	83	84	48	9	59	109
Other softwoods	0	0	1	0	0	2	0	0	0	0	0	0	0
Total softwoods	134	27	37	72	104	152	120	253	217	156	84	217	268
Hardwoods													
Select white oak	13	9	14	3	16	8	6	8	27	23	28	25	2
Select red oak	13	2	2	1	5	13	21	16	23	19	33	35	3
Other red oak	6	3	5	0	8	9	1	0	33	0	0	3	0
Hickory	0	0	0	0	0	1	0	0	1	2	0	0	0
Yellow birch	15	0	1	17	12	8	20	26	18	21	3	41	55
Hard maple	11	1	6	5	12	9	21	17	14	10	26	20	6
Soft maple	214	37	68	109	194	213	311	246	359	295	317	340	262
Beech	0	0	0	0	0	0	0	0	3	1	0	0	0
Ash	271	59	64	277	305	240	269	331	375	361	558	412	413
Balsam poplar	5	2	1	5	13	7	1	16	2	0	0	3	0
Cottonwood	9	5	6	6	0	27	9	2	6	22	0	0	28
Bigtooth aspen	3	4	4	0	0	9	9	1	1	0	0	0	0
Quaking aspen	48	35	22	47	89	96	75	36	25	10	78	19	0
Basswood	23	4	2	4	4	38	19	24	50	34	36	64	22
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	2	0	0	0	0	0	0	0	0	0	0	0
Black cherry	2	1	1	0	1	7	2	3	0	4	0	0	0
Butternut	0	0	0	0	0	0	0	0	1	0	0	0	0
Elm	73	18	15	59	56	59	65	102	93	114	168	118	187
Paper birch	31	12	19	26	45	36	47	47	33	43	10	21	6
Other hardwoods	23	16	30	7	26	28	46	5	8	68	7	38	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	760	210	260	566	786	808	922	880	1,072	1,027	1,264	1,139	984
Total all species	894	237	297	638	890	960	1,042	1,133	1,289	1,183	1,348	1,356	1,252
Number of plots	606	77	56	40	56	76	59	67	60	42	26	26	21
Standard error	94	91	118	228	300	285	334	366	381	401	551	596	605
Average basal area	75	29	43	60	73	81	83	88	97	93	99	105	99

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 11.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Maple-birch All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	31	4	18	16	27	17	27	38	40	43	71	26	80
Red pine	4	4	4	2	2	0	5	4	7	0	7	4	13
Jack pine	1	2	4	2	0	0	1	0	6	0	0	0	0
White spruce	5	0	2	2	4	5	6	7	6	4	11	6	3
Black spruce	0	0	0	0	1	1	0	1	0	0	0	3	0
Balsam fir	28	12	19	16	37	37	30	38	29	24	11	27	29
Hemlock	65	3	10	4	15	15	20	29	33	55	115	229	433
Tamarack	1	0	1	0	0	1	1	2	0	0	0	0	2
Northern white-cedar	13	1	2	2	3	5	10	19	11	12	24	32	56
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	148	26	60	44	89	81	100	138	132	138	239	327	616
Hardwoods													
Select white oak	17	10	24	16	19	10	14	13	24	28	31	25	12
Select red oak	69	18	35	49	68	67	90	76	76	107	98	79	60
Other red oak	6	3	13	19	3	2	8	3	6	0	8	2	3
Hickory	11	5	11	12	18	15	11	4	9	14	9	17	11
Yellow birch	41	3	6	4	21	22	28	44	35	68	91	93	141
Hard maple	339	58	52	107	215	303	355	433	479	520	520	513	606
Soft maple	138	43	68	84	158	190	180	183	140	133	159	129	59
Beech	6	1	0	13	1	1	0	5	3	10	2	26	32
Ash	68	15	10	46	58	87	86	99	108	83	66	64	38
Balsam poplar	0	0	0	0	3	1	1	0	2	0	1	0	0
Cottonwood	0	1	2	2	0	0	0	0	0	1	1	5	0
Bigtooth aspen	22	4	8	10	27	32	46	20	39	17	17	8	0
Quaking aspen	70	27	56	95	126	114	101	73	44	38	20	25	7
Basswood	171	20	33	84	126	237	223	269	196	219	155	133	133
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	2	2	0	1	0	2	0	0	1	0
Black cherry	16	8	17	17	27	22	17	13	31	16	12	12	2
Butternut	4	1	5	8	2	1	2	2	7	5	11	5	2
Elm	62	14	24	42	58	58	65	83	91	83	71	71	91
Paper birch	53	11	24	38	55	61	79	80	39	50	75	46	19
Other hardwoods	2	0	1	0	16	0	1	4	3	3	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,095	242	389	648	1,003	1,223	1,308	1,404	1,334	1,395	1,347	1,254	1,216
Total all species	1,243	268	449	692	1,092	1,304	1,408	1,542	1,466	1,533	1,586	1,581	1,832
Number of plots	1,887	156	130	111	113	281	313	234	116	112	73	117	131
Standard error	152	119	142	207	350	447	510	557	519	549	588	505	741
Average basal area	93	34	57	74	89	102	105	110	104	103	103	104	110

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 12.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Aspen All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	14	6	6	5	10	9	29	37	53	114	0	0	0
Red pine	16	11	6	15	10	8	37	32	50	49	0	0	0
Jack pine	13	7	9	14	17	20	9	20	8	13	0	0	0
White spruce	10	5	5	8	10	12	17	13	13	42	0	0	0
Black spruce	3	1	2	2	2	3	6	1	0	0	0	0	0
Balsam fir	33	10	8	23	48	42	45	74	65	65	0	0	0
Hemlock	1	1	0	0	1	0	0	0	13	12	0	0	0
Tamarack	2	1	2	0	2	2	2	0	31	0	0	0	0
Northern white-cedar	4	1	0	1	2	2	10	7	44	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	96	43	38	68	102	98	155	184	277	295	0	0	0
Hardwoods													
Select white oak	8	5	6	6	13	8	8	21	19	9	34	0	0
Select red oak	34	8	12	21	22	45	70	90	20	129	496	0	0
Other red oak	11	7	3	7	8	15	15	9	72	19	201	0	0
Hickory	0	0	0	1	1	0	0	4	0	0	0	0	0
Yellow birch	1	0	0	1	1	0	2	2	2	8	0	0	0
Hard maple	14	8	4	19	9	18	23	23	9	30	0	0	0
Soft maple	59	27	28	33	61	89	86	108	61	150	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	11	5	4	8	20	13	15	21	13	0	0	0	0
Balsam poplar	7	1	2	0	7	6	18	18	13	46	0	0	0
Cottonwood	0	1	0	1	0	0	3	0	0	0	0	0	0
Bigtooth aspen	115	18	19	49	98	188	257	202	240	157	868	0	0
Quaking aspen	392	94	139	321	576	630	536	522	365	552	52	0	0
Basswood	8	2	10	2	8	11	11	10	3	5	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	7	2	4	8	10	11	4	5	11	0	0	0	0
Butternut	0	0	0	0	0	0	1	2	0	0	0	0	0
Elm	6	3	2	6	10	5	9	19	3	3	85	0	0
Paper birch	83	23	26	60	94	119	168	108	93	82	83	0	0
Other hardwoods	0	0	0	0	2	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	756	204	259	543	940	1,158	1,226	1,164	924	1,190	1,819	0	0
Total all species	852	247	297	611	1,042	1,256	1,381	1,348	1,201	1,485	1,819	0	0
Number of plots	1,608	322	223	156	229	337	209	77	35	18	2	0	0
Standard error	125	108	116	219	347	422	470	471	470	660	3/	0	0
Average basal area	68	29	43	60	79	92	97	98	83	100	100	0	0

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

[3/] Insufficient number of plots to compute the standard error.

Table 13.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Forest type - Paper birch All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	25	19	4	3	42	9	40	42	36	91	0	0	0
Red pine	25	18	3	19	12	11	24	63	160	0	0	0	0
Jack pine	5	0	0	3	10	9	5	0	0	0	0	0	0
White spruce	17	0	0	32	2	15	26	18	5	751	0	44	0
Black spruce	4	7	0	3	0	2	12	4	0	0	0	0	0
Balsam fir	54	4	3	21	37	72	63	99	88	0	279	53	0
Hemlock	6	0	0	3	7	0	5	16	18	0	497	0	0
Tamarack	4	0	19	8	2	1	3	5	9	0	0	0	0
Northern white-cedar	14	0	11	3	12	24	5	17	63	0	0	42	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	154	48	40	95	124	143	183	264	379	842	776	139	0
Hardwoods													
Select white oak	12	13	44	1	22	9	3	11	10	0	0	31	0
Select red oak	85	24	31	30	73	79	138	143	89	0	0	0	0
Other red oak	4	0	0	0	10	5	3	2	32	0	0	0	0
Hickory	3	2	2	10	10	5	0	0	0	0	0	0	0
Yellow birch	4	0	0	7	1	2	7	2	13	0	161	0	0
Hard maple	26	2	4	3	16	20	57	37	49	0	0	0	0
Soft maple	83	18	50	54	47	102	123	102	65	0	610	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	15	0	2	8	27	19	10	19	55	0	0	38	0
Balsam poplar	2	5	0	0	3	1	0	2	0	0	0	84	0
Cottonwood	0	0	0	3	0	0	0	0	0	0	0	0	0
Bigtooth aspen	43	2	16	25	46	32	71	55	148	0	0	0	0
Quaking aspen	131	38	32	124	114	180	160	142	139	67	72	104	0
Basswood	11	0	8	6	9	14	19	5	0	0	0	81	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	4	0	0	2	5	5	5	6	8	0	0	0	0
Butternut	0	0	0	0	3	0	0	0	0	0	0	0	0
Elm	7	5	8	4	17	10	1	4	9	0	0	0	0
Paper birch	563	133	247	307	633	651	672	793	699	142	1,439	214	0
Other hardwoods	0	0	0	0	3	0	0	0	10	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	993	242	444	584	1,039	1,134	1,269	1,323	1,326	209	2,282	552	0
Total all species	1,147	290	484	679	1,163	1,277	1,452	1,587	1,705	1,051	3,058	691	0
Number of plots	322	27	26	29	41	78	68	40	9	1	1	2	0
Standard error	202	125	188	266	384	499	528	822	877	3/	3/	3/	0
Average basal area	88	28	54	69	87	100	103	113	110	56	155	57	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 14.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Jack pine   All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	34	0	2	4	9	15	26	42	84	189	127	316	0
Red pine	161	23	25	71	114	179	160	164	271	305	637	629	0
Jack pine	930	133	237	571	870	1,073	1,152	1,113	1,067	968	744	693	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	1	0	1	1	1	1	0	1	0	4	24	57	0
Balsam fir	0	0	0	0	0	0	0	0	0	1	6	35	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	3	15	31	0
Total softwoods	1,126	156	265	647	994	1,268	1,338	1,320	1,422	1,470	1,553	1,761	0
Hardwoods													
Select white oak	3	2	1	1	2	2	3	5	6	0	0	0	0
Select red oak	12	0	1	0	7	10	15	25	16	7	35	88	0
Other red oak	32	3	7	11	15	31	36	39	68	44	83	133	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	3	0	0	1	1	2	4	7	11	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	10	2	10	7	7	9	9	13	22	10	0	0	0
Quaking aspen	66	3	3	40	75	62	69	100	65	100	84	85	0
Basswood	0	0	0	0	0	0	0	0	2	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	3	12	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	1	1	0	0	0	0	0
Paper birch	8	0	1	2	3	9	7	10	21	9	45	94	0
Other hardwoods	1	0	0	0	0	0	1	2	5	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	135	10	23	62	110	125	145	202	219	182	247	400	0
Total all species	1,261	166	288	709	1,104	1,393	1,483	1,522	1,641	1,652	1,800	2,161	0
Number of plots	1,043	19	66	104	163	202	184	151	97	39	11	7	0
Standard error	111	94	132	229	258	299	293	323	431	465	793	1,245	0
Average basal area	92	22	46	71	92	105	103	98	102	96	101	109	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 15.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Red pine   All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	150	2	12	25	43	83	124	229	432	474	575	826	915
Red pine	2,450	66	445	1,461	2,305	3,282	3,810	3,529	2,762	2,426	1,793	1,882	1,773
Jack pine	42	2	6	32	47	51	42	54	76	81	44	29	26
White spruce	20	6	3	11	21	27	9	4	4	23	51	84	225
Black spruce	2	0	0	3	1	1	2	3	7	7	13	10	0
Balsam fir	12	0	0	0	3	5	10	25	22	32	61	62	147
Hemlock	4	0	0	0	0	0	0	0	5	16	47	54	40
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	2	0	0	0	0	0	0	0	0	10	23	45	23
Other softwoods	7	0	4	6	7	9	4	6	15	28	0	0	0
Total softwoods	2,689	76	470	1,538	2,427	3,458	4,001	3,850	3,323	3,097	2,607	2,992	3,149
Hardwoods													
Select white oak	1	0	1	1	1	5	0	0	0	0	0	0	0
Select red oak	14	2	5	4	4	3	17	23	45	100	49	51	8
Other red oak	12	0	17	17	18	16	10	1	3	0	3	2	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	3	6	10
Hard maple	9	0	4	3	3	5	12	25	8	14	27	39	27
Soft maple	19	0	2	1	2	8	19	38	50	34	60	109	227
Beech	0	0	2	1	0	0	0	0	0	0	0	0	0
Ash	1	0	3	2	0	1	0	1	4	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	7	0	1	2	4	3	4	3	13	32	62	56	0
Quaking aspen	48	0	17	18	48	54	58	72	64	77	84	82	47
Basswood	0	0	1	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1	3	1	1	1	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	0	0	1	3	6	0	2	5	7
Paper birch	16	14	9	7	8	5	8	11	24	58	53	101	140
Other hardwoods	2	0	0	5	5	1	1	3	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	131	19	63	62	94	101	130	180	217	315	343	451	466
Total all species	2,820	95	533	1,600	2,521	3,559	4,131	4,030	3,540	3,412	2,950	3,443	3,615
Number of plots	844	24	71	122	162	155	119	72	37	24	19	28	11
Standard error	270	76	187	449	584	795	1,014	1,145	1,247	1,022	960	902	1,152
Average basal area	160	9	50	109	154	204	224	208	182	172	146	161	170

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 16.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - White pine All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,545	208	370	640	871	1,144	1,205	1,416	1,650	1,535	1,822	2,135	2,512
Red pine	296	73	120	208	262	393	396	444	402	319	311	210	173
Jack pine	49	0	0	15	33	72	99	87	83	68	21	19	22
White spruce	38	12	8	34	41	54	9	3	36	54	81	79	5
Black spruce	17	0	0	17	20	35	53	7	8	18	20	17	2
Balsam fir	62	0	0	5	8	12	2	5	33	75	122	160	125
Hemlock	18	0	0	0	0	9	10	11	19	9	15	20	64
Tamarack	5	0	0	0	0	0	9	9	9	6	4	8	6
Northern white-cedar	10	0	0	0	0	0	0	0	0	1	2	7	74
Other softwoods	1	0	0	0	0	0	3	4	5	5	0	0	0
Total softwoods	2,041	293	498	919	1,235	1,719	1,786	1,986	2,245	2,090	2,398	2,655	2,983
Hardwoods													
Select white oak	17	0	0	0	1	7	16	21	25	25	21	23	23
Select red oak	17	0	0	0	0	0	2	8	17	21	22	17	58
Other red oak	31	0	0	10	13	12	15	41	51	48	58	29	32
Hickory	2	0	0	0	4	6	7	8	0	0	0	0	0
Yellow birch	2	0	9	13	6	9	0	0	0	0	0	0	0
Hard maple	10	0	9	8	7	8	0	0	0	0	0	27	39
Soft maple	68	0	3	17	18	13	14	37	62	80	106	106	163
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	5	0	0	0	0	0	0	0	1	4	4	21	10
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	25	0	0	104	84	84	75	0	2	2	4	3	0
Bigtooth aspen	25	0	0	4	6	12	19	14	42	47	64	38	0
Quaking aspen	148	22	48	91	137	189	203	195	177	190	132	149	78
Basswood	4	0	0	0	0	0	4	5	5	8	2	5	13
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	5	0	8	8	20	3	3	3	0	0	0	11	6
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	3	4	3	3	5	5	2	0	1	0	0
Paper birch	58	0	0	0	6	27	49	54	72	71	66	97	93
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	419	22	80	259	305	373	412	391	456	496	480	526	515
Total all species	2,460	315	578	1,178	1,540	2,092	2,198	2,377	2,701	2,586	2,878	3,181	3,498
Number of plots	452	9	17	23	32	34	38	42	48	52	42	56	59
Standard error	200	179	210	346	369	480	513	540	650	648	844	742	734
Average basal area	138	28	64	99	120	147	140	146	148	139	145	158	155

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 17.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Exotic   All sites

(In cubic feet per acre)

		Stand-age class (years)											
Species group	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	0	0	0	0	0	0	0	0	0	0	0	0	0
Red pine	770	0	0	292	1,189	1,602	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	1,003	0	244	831	1,270	1,667	0	0	0	0	0	0	0
Total softwoods	1,773	0	244	1,123	2,459	3,269	0	0	0	0	0	0	0
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total all species	1,773	0	244	1,123	2,459	3,269	0	0	0	0	0	0	0
Number of plots	4	0	1	1	1	1	0	0	0	0	0	0	0
Standard error	1,199	0	3/	3/	3/	3/	0	0	0	0	0	0	0
Average basal area	161	0	72	133	198	244	0	0	0	0	0	0	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 18.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Black spruce All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	42	0	3	15	33	63	37	49	51	49	73	133	25
Red pine	28	8	17	21	34	39	16	17	32	49	41	50	0
Jack pine	1	0	0	0	0	0	1	3	4	2	4	0	0
White spruce	7	0	0	0	1	3	5	4	16	19	36	51	0
Black spruce	250	59	64	94	141	225	308	392	470	566	449	367	106
Balsam fir	63	17	23	26	38	37	64	75	134	161	163	159	21
Hemlock	11	0	3	2	2	2	0	0	6	25	61	136	120
Tamarack	76	44	53	50	43	57	113	128	109	120	86	60	133
Northern white-cedar	24	0	12	7	9	16	8	23	52	51	87	119	136
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	502	128	175	215	301	442	552	691	874	1,042	1,000	1,075	541
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	5	0	1	5	5	9	5	7	7	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	1	2	3	4	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	0	1	1	1	2	1	1	0	0	0	0
Hard maple	3	0	0	0	3	5	9	0	1	2	3	4	0
Soft maple	17	0	1	2	7	14	15	30	58	50	25	23	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	1	0	0	0	0	0	0	2	4	4	8	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	5	0	0	5	7	7	10	2	1	0	0	0	0
Quaking aspen	77	41	38	49	81	109	105	100	102	73	10	14	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	3	10	27
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	28	0	6	16	29	44	34	32	39	28	27	10	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	137	41	46	78	133	189	180	174	214	159	79	65	27
Total all species	639	169	221	293	434	631	732	865	1,088	1,201	1,079	1,140	568
Number of plots	568	16	39	77	95	95	80	50	39	28	22	21	6
Standard error	70	115	96	108	141	196	268	256	301	368	366	387	394
Average basal area	69	30	41	52	61	77	76	82	89	99	81	80	39

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

cubic feet volume per acre in growing-stock trees by species group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Balsam fir   All sites

(In cubic feet per acre)

Species group	Average 2/	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	48	26	20	20	21	20	34	42	62	61	36	144	297
Red pine	17	5	9	15	19	31	8	10	15	26	14	39	19
Jack pine	1	9	7	3	1	0	0	0	0	0	0	0	0
White spruce	165	14	30	47	83	121	163	196	246	292	169	270	219
Black spruce	38	29	26	17	19	33	42	51	55	42	41	42	35
Balsam fir	699	100	188	327	494	614	763	875	974	1,008	861	725	493
Hemlock	22	8	7	8	12	11	15	18	19	22	25	40	217
Tamarack	14	3	6	9	9	7	10	12	15	21	17	34	60
Northern white-cedar	135	36	60	79	106	131	115	139	131	163	219	216	382
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	1,139	230	353	525	764	968	1,150	1,343	1,517	1,635	1,382	1,510	1,722
Hardwoods													
Select white oak	0	1	1	1	1	0	0	0	0	0	0	0	0
Select red oak	1	2	1	1	1	3	1	2	1	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	13	1	2	4	7	15	11	12	13	15	26	44	32
Hard maple	11	6	6	10	14	15	18	10	13	10	1	6	0
Soft maple	54	13	18	33	43	48	49	55	58	57	54	185	83
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	37	24	23	22	21	42	31	43	39	51	89	33	0
Balsam poplar	7	0	0	0	0	1	7	12	16	26	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	6	4	13	12	12	14	2	3	4	4	0	0	4
Quaking aspen	135	23	57	82	108	184	155	160	180	124	75	132	228
Basswood	0	0	0	1	1	1	1	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	19	0	7	7	7	6	14	13	49	63	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	7	0	0	0	1	6	9	11	10	7	13	0	9
Paper birch	67	23	40	40	47	59	73	71	81	104	111	62	33
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	357	97	168	213	263	394	371	392	464	461	369	462	389
Total all species	1,496	327	521	738	1,027	1,362	1,521	1,735	1,981	2,096	1,751	1,972	2,111
Number of plots	852	29	45	69	85	83	116	119	111	92	45	35	23
Standard error	117	157	187	200	229	278	293	357	444	562	515	435	502
Average basal area	111	33	54	72	92	114	118	125	135	135	120	128	141

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 20.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Northern white-cedar All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	36	19	16	15	24	10	18	23	25	25	28	39	74
Red pine	1	0	0	0	0	2	2	2	1	0	0	1	2
Jack pine	1	0	0	0	0	0	0	0	3	4	4	3	0
White spruce	37	0	6	8	10	13	33	51	68	67	37	32	29
Black spruce	41	41	38	38	51	33	37	50	45	42	42	28	47
Balsam fir	124	8	26	30	27	77	150	176	188	153	121	115	113
Hemlock	39	11	5	3	4	1	9	13	14	20	25	30	117
Tamarack	33	0	6	24	21	70	69	61	57	34	38	15	9
Northern white-cedar	1,087	169	289	342	515	733	859	953	1,130	1,122	1,160	1,214	1,423
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	1,399	248	386	460	652	939	1,177	1,329	1,531	1,467	1,455	1,477	1,814
Hardwoods													
Select white oak	0	14	6	4	4	0	0	0	0	0	0	0	0
Select red oak	0	0	0	3	2	2	1	0	1	1	1	0	0
Other red oak	0	0	0	2	2	0	0	0	0	1	0	0	0
Hickory	1	15	7	4	4	2	2	2	1	0	0	1	1
Yellow birch	25	0	0	0	0	0	9	16	14	16	23	25	59
Hard maple	0	0	0	0	0	0	0	0	0	0	2	1	1
Soft maple	32	0	70	60	61	49	31	34	19	28	21	30	31
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	44	0	0	6	9	20	31	34	38	51	51	51	63
Balsam poplar	1	0	0	0	0	1	1	1	1	0	5	3	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	4	0	0	0	0	0	11	9	10	14	1	0	0
Quaking aspen	29	13	41	29	41	67	55	55	42	41	15	14	3
Basswood	3	12	9	8	10	0	0	0	0	0	4	7	3
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	6	0	5	5	6	7	3	12	12	8	6	6	3
Paper birch	65	16	41	45	85	103	103	98	86	66	47	52	40
Other hardwoods	0	0	0	0	3	2	2	2	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	210	70	179	166	227	253	249	263	224	226	176	190	204
Total all species	1,609	318	565	626	879	1,192	1,426	1,592	1,755	1,693	1,631	1,667	2,018
Number of plots	684	4	11	21	25	41	50	59	70	65	71	115	152
Standard error	190	295	274	230	294	348	396	478	515	560	620	512	574
Average basal area	150	39	70	94	110	131	139	147	154	155	161	159	168

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 21.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Tamarack All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	60	28	31	41	65	61	30	30	53	67	112	176	102
Red pine	2	0	0	1	1	2	3	2	5	6	10	6	0
Jack pine	5	0	0	0	1	4	12	17	23	0	0	0	0
White spruce	19	7	3	2	9	18	46	17	30	32	11	0	115
Black spruce	67	25	21	36	59	90	112	96	76	71	56	85	57
Balsam fir	53	1	14	18	29	55	67	116	167	47	37	80	0
Hemlock	0	0	0	0	0	0	0	0	0	1	2	6	0
Tamarack	438	174	145	168	255	366	527	682	732	786	810	579	631
Northern white-cedar	14	0	0	0	0	0	5	13	23	39	49	98	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	658	235	214	266	419	596	802	973	1,109	1,049	1,087	1,030	905
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	4	2	1	2	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1	0	1	1	1	1	3	0	1	1	3	4	0
Hard maple	0	0	1	1	1	2	0	0	0	0	0	0	0
Soft maple	31	7	7	14	25	36	42	32	66	55	45	31	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	6	0	0	0	0	0	0	6	9	13	50	27	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	14	17	9	8	10	11	29	62	23	0	0	0	0
Quaking aspen	33	0	11	14	19	54	54	59	70	25	42	9	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	2	0	0	0	0	3	5	7	3	1	2	12	0
Paper birch	44	36	27	23	34	28	39	82	121	49	57	29	19
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	131	64	58	62	92	135	172	248	293	144	199	112	19
Total all species	789	299	272	328	511	731	974	1,221	1,402	1,193	1,286	1,142	924
Number of plots	476	16	42	64	71	64	47	35	36	35	26	28	12
Standard error	77	141	89	93	137	226	363	369	419	325	378	343	355
Average basal area	63	29	30	41	52	63	75	86	93	84	84	80	62

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 22.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - White spruce All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	69	0	31	31	32	42	9	81	167	433	1,615	0	0
Red pine	33	0	11	24	39	61	47	39	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	2,105	0	191	1,243	2,431	3,330	3,233	2,168	2,029	1,899	2,692	0	0
Black spruce	3	0	0	0	7	4	6	0	0	0	0	0	0
Balsam fir	71	0	6	6	25	54	91	164	196	357	443	0	0
Hemlock	3	0	6	5	4	5	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	31	0	0	0	21	42	63	106	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	2,315	0	245	1,309	2,559	3,538	3,449	2,558	2,392	2,689	4,750	0	0
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	5	0	10	10	9	5	0	0	0	0	0	0	0
Hard maple	13	0	14	12	7	12	6	29	41	0	0	0	0
Soft maple	19	0	0	0	21	28	41	47	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	16	0	0	0	6	25	26	45	49	0	0	0	0
Balsam poplar	15	0	0	0	0	0	12	25	75	239	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	5	0	0	0	0	5	9	14	34	0	0	0	0
Quaking aspen	52	40	48	51	43	38	61	56	99	47	175	0	0
Basswood	4	0	0	0	0	3	7	11	25	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	5	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	4	0	8	11	4	5	0	0	0	0	0	0	0
Paper birch	13	0	0	0	0	0	0	23	52	123	421	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	146	40	85	84	90	121	162	250	375	409	596	0	0
Total all species	2,461	40	330	1,393	2,649	3,659	3,611	2,808	2,767	3,098	5,346	0	0
Number of plots	104	5	11	15	20	18	14	11	6	3	1	0	0
Standard error	416	45	166	616	1,012	1,389	1,710	1,125	1,324	2,308	3/	0	0
Average basal area	144	7	47	112	168	202	191	146	143	150	207	0	0

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

[3] Insufficient number of plots to compute the standard error.

Table 23.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Oak-hickory   All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	36	10	16	26	36	17	16	21	33	46	59	57	46
Red pine	23	6	15	26	40	29	20	28	16	24	32	39	3
Jack pine	41	40	61	73	92	75	60	57	37	31	22	16	6
White spruce	1	0	0	0	1	5	6	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	1	0	0	1	3	1	0	1	0	1	1	0	0
Hemlock	0	0	0	0	0	0	0	0	0	1	1	1	0
Tamarack	0	0	0	0	0	0	0	0	0	0	1	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	1	2	2	0	0	0	1	1	0	0
Total softwoods	102	56	92	127	174	129	102	107	86	104	117	113	55
Hardwoods													
Select white oak	220	27	38	53	81	122	140	173	196	239	293	363	420
Select red oak	420	38	60	86	117	245	392	446	518	573	511	622	536
Other red oak	220	81	90	116	164	235	268	299	292	280	276	205	137
Hickory	55	14	17	31	43	65	55	64	58	56	61	68	65
Yellow birch	0	0	0	0	0	0	0	0	0	0	1	0	0
Hard maple	27	2	2	2	5	6	10	16	24	32	44	56	52
Soft maple	61	3	9	12	21	33	61	72	91	86	76	80	64
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	17	0	2	3	4	7	12	16	22	29	24	27	21
Balsam poplar	0	0	0	0	0	0	1	2	2	2	0	0	0
Cottonwood	2	0	1	1	2	3	3	4	4	3	3	3	1
Bigtooth aspen	76	12	16	23	34	51	85	102	123	127	103	80	39
Quaking aspen	49	12	29	42	56	66	80	77	79	59	33	21	20
Basswood	36	2	6	10	14	17	24	29	34	42	44	61	63
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	7	6	6	7	8	1	3	4	5	7	7	9	13
Black cherry	33	3	8	15	27	36	36	38	35	31	36	46	35
Butternut	7	4	4	5	8	7	10	12	9	6	2	4	7
Elm	19	9	10	12	16	15	15	16	19	22	27	29	20
Paper birch	57	7	10	19	35	55	77	86	83	85	68	42	41
Other hardwoods	3	0	0	3	6	5	3	4	2	4	4	2	4
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,309	220	308	440	641	969	1,275	1,460	1,596	1,683	1,613	1,718	1,538
Total all species	1,411	276	400	567	815	1,098	1,377	1,567	1,682	1,787	1,730	1,831	1,593
Number of plots	4,796	148	213	254	307	301	413	488	552	500	387	601	632
Standard error	75	116	138	164	190	214	255	272	284	305	275	225	196
Average basal area	105	38	48	61	76	95	106	116	121	124	122	122	116

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 24.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Elm-ash-soft maple All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	31	1	4	8	13	20	31	38	42	48	57	44	29
Red pine	0	1	0	0	0	0	0	0	1	1	0	0	0
Jack pine	1	0	0	0	1	1	3	3	3	1	0	0	0
White spruce	17	1	2	4	8	15	18	27	23	19	28	26	16
Black spruce	2	0	0	0	1	2	4	5	1	2	0	1	1
Balsam fir	79	6	8	23	40	73	93	121	126	107	95	74	85
Hemlock	21	0	2	3	3	5	6	12	20	27	39	46	75
Tamarack	11	3	4	7	10	11	13	16	16	17	14	7	0
Northern white-cedar	59	15	17	24	30	31	39	58	78	83	104	78	116
Other softwoods	1	0	0	0	1	2	3	4	5	0	0	0	0
Total softwoods	222	27	37	69	107	160	210	284	315	305	337	276	322
Hardwoods													
Select white oak	18	9	14	14	18	14	12	14	15	19	27	37	20
Select red oak	18	2	2	1	6	7	13	20	25	27	31	38	29
Other red oak	8	3	4	3	5	6	7	8	12	11	15	12	1
Hickory	0	0	0	0	2	2	0	0	0	0	0	0	0
Yellow birch	18	0	0	5	9	15	21	21	21	22	25	25	34
Hard maple	23	1	3	8	12	23	25	30	31	30	30	31	21
Soft maple	340	37	72	129	201	280	332	392	426	449	462	506	438
Beech	0	0	0	0	0	0	0	0	0	1	2	3	0
Ash	363	59	80	168	255	341	411	407	414	423	471	505	484
Balsam poplar	7	2	3	5	8	10	11	11	9	8	10	0	2
Cottonwood	13	5	6	7	7	14	16	17	22	12	9	11	16
Bigtooth aspen	5	4	5	6	6	6	7	8	9	5	2	0	0
Quaking aspen	75	35	33	54	78	106	125	119	110	57	50	35	15
Basswood	36	4	6	8	9	18	24	34	44	50	65	77	61
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	2	1	1	1	0	0	0	0	0	0	0	0
Black cherry	3	1	1	1	1	9	4	5	5	3	3	1	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	85	18	27	48	63	68	87	94	89	108	117	116	123
Paper birch	48	12	18	32	46	57	62	68	62	58	48	39	16
Other hardwoods	40	16	33	43	57	45	41	45	39	42	25	47	15
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,100	210	308	533	784	1,021	1,198	1,293	1,333	1,325	1,392	1,483	1,275
Total all species	1,322	237	345	602	891	1,181	1,408	1,577	1,648	1,630	1,729	1,759	1,597
Number of plots	2,424	77	133	173	229	228	231	258	262	228	195	245	165
Standard error	69	91	100	141	168	202	235	259	265	259	289	243	262
Average basal area	97	29	43	60	77	93	103	110	114	114	117	120	114

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 25.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, All Units, Wisconsin, 1983[1]

Data from a 30-year projection

Forest type - Maple-birch   All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	52	4	12	20	34	43	35	42	50	65	79	72	90
Red pine	7	4	6	9	11	9	3	4	5	8	7	5	14
Jack pine	2	2	3	7	9	8	1	0	1	1	1	0	0
White spruce	14	0	2	3	6	9	12	17	19	17	23	16	14
Black spruce	1	0	0	1	1	1	1	1	1	1	0	1	0
Balsam fir	44	12	23	34	46	50	48	54	55	51	46	35	29
Hemlock	83	3	6	7	10	15	18	24	31	40	60	142	448
Tamarack	1	0	0	0	1	1	1	1	2	2	1	0	1
Northern white-cedar	19	1	2	3	4	5	8	13	17	21	25	29	60
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	223	26	54	84	122	141	127	156	181	206	242	300	656
Hardwoods													
Select white oak	23	10	18	20	24	21	17	17	20	25	29	38	26
Select red oak	93	18	30	45	60	76	92	99	112	120	119	126	90
Other red oak	8	3	8	15	15	12	9	6	7	8	6	5	3
Hickory	16	5	8	13	18	23	21	19	17	12	11	17	17
Yellow birch	47	3	5	5	12	22	25	36	41	49	62	81	132
Hard maple	523	58	84	125	201	277	382	517	634	704	756	759	831
Soft maple	225	43	80	135	203	233	239	271	312	279	255	211	140
Beech	9	1	1	4	4	5	4	2	3	5	6	16	38
Ash	98	15	19	34	54	80	106	119	138	132	136	113	68
Balsam poplar	1	0	0	0	0	1	3	3	1	1	1	0	0
Cottonwood	1	1	1	2	2	1	0	0	0	0	0	2	1
Bigtooth aspen	32	4	8	11	17	28	42	48	50	49	37	30	4
Quaking aspen	95	27	47	87	129	151	135	134	121	109	62	35	14
Basswood	249	20	31	57	92	189	259	325	374	363	352	258	181
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	1	0	0	0	1	1	1	0	1	1	1	1	1
Black cherry	27	8	15	24	36	36	31	29	30	29	29	27	14
Butternut	6	1	5	8	10	10	5	3	4	5	7	9	6
Elm	71	14	25	42	59	70	74	83	77	78	77	75	82
Paper birch	73	11	25	43	62	73	81	93	95	94	87	68	39
Other hardwoods	4	0	0	1	5	5	5	7	3	4	5	4	1
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,602	242	410	671	1,004	1,314	1,531	1,811	2,040	2,067	2,038	1,875	1,688
Total all species	1,825	268	464	755	1,126	1,455	1,658	1,967	2,221	2,273	2,280	2,175	2,344
Number of plots	7,548	156	286	397	510	635	818	941	944	775	535	714	837
Standard error	109	119	136	167	203	254	300	354	419	467	464	291	332
Average basal area	121	34	55	74	95	111	119	131	141	141	139	131	134

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 26.--Cubic foot volume per acre in growing-stock trees by species[1/] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Aspen All sites

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	27	6	9	13	17	15	22	34	46	78	103	157	0
Red pine	34	11	17	26	35	23	29	39	44	78	93	81	0
Jack pine	21	7	11	17	23	26	24	23	22	15	30	18	0
White spruce	41	5	10	22	36	33	44	58	69	78	56	82	0
Black spruce	5	1	3	4	5	5	6	6	7	7	3	0	0
Balsam fir	68	10	19	34	56	60	79	97	110	113	123	114	0
Hemlock	1	1	0	0	1	0	0	1	1	2	7	17	0
Tamarack	3	1	2	2	3	2	2	3	4	5	10	15	0
Northern white-cedar	7	1	2	3	4	3	6	9	14	25	24	37	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	207	43	73	121	180	167	212	270	317	401	449	521	0
Hardwoods													
Select white oak	13	5	6	8	11	12	14	18	17	20	30	25	60
Select red oak	52	8	14	22	28	39	56	72	91	128	131	149	762
Other red oak	16	7	7	10	12	13	17	18	26	26	37	62	114
Hickory	1	0	0	2	2	1	1	1	0	1	3	0	0
Yellow birch	2	0	0	1	2	1	1	2	3	5	7	2	0
Hard maple	30	8	9	16	21	22	30	40	54	66	68	68	0
Soft maple	124	27	49	73	105	112	127	165	199	215	230	220	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	18	5	6	11	17	19	20	23	22	25	30	11	0
Balsam poplar	10	1	2	2	4	6	12	16	17	26	25	54	0
Cottonwood	1	1	1	2	2	0	1	1	2	4	0	0	0
Bigtooth aspen	186	18	27	48	83	147	229	302	377	393	333	401	1,188
Quaking aspen	625	94	169	321	499	748	810	915	882	715	744	586	102
Basswood	14	2	6	8	12	18	14	18	22	22	20	9	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	14	2	4	9	15	17	18	20	18	10	13	9	0
Butternut	0	0	0	0	0	0	0	1	1	2	3	0	0
Elm	10	3	4	7	11	9	11	11	11	15	17	11	147
Paper birch	131	23	33	59	90	118	163	201	221	235	167	158	147
Other hardwoods	1	0	0	0	1	1	1	1	1	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,248	204	337	599	915	1,283	1,525	1,825	1,964	1,908	1,858	1,765	2,520
Total all species	1,455	247	410	720	1,095	1,450	1,737	2,095	2,281	2,309	2,307	2,286	2,520
Number of plots	6,432	322	545	701	930	945	931	852	658	339	132	75	2
Standard error	106	108	134	178	202	260	310	403	505	558	552	526	3/
Average basal area	97	29	44	64	80	99	112	129	136	139	136	128	117

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 27.--Cubic foot volume per acre in growing-stock trees by species[1] group and stand-age class, All Units, Wisconsin, 1983

Data from a 30-year projection

Forest type - Paper birch All sites

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	48	19	17	21	37	26	34	51	55	110	120	80	0
Red pine	40	18	15	18	20	14	21	33	52	82	176	184	0
Jack pine	5	0	0	1	4	8	9	7	5	2	0	0	0
White spruce	47	0	0	11	15	23	40	47	81	109	64	140	68
Black spruce	6	7	5	5	3	1	6	6	8	15	0	0	0
Balsam fir	99	4	10	20	44	73	94	119	159	166	142	64	156
Hemlock	8	0	0	1	3	3	4	7	7	13	35	94	68
Tamarack	7	0	13	14	12	7	4	4	4	7	11	25	0
Northern white-cedar	20	0	5	6	8	19	18	23	29	21	42	62	52
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	280	48	65	97	146	174	230	297	400	525	590	649	344
Hardwoods													
Select white oak	17	13	31	25	28	23	11	14	11	10	18	14	50
Select red oak	115	24	32	36	57	75	113	142	162	199	201	92	0
Other red oak	5	0	0	0	3	5	6	5	5	7	9	37	0
Hickory	5	2	3	5	8	10	8	5	1	0	0	0	0
Yellow birch	4	0	0	2	1	3	3	4	7	7	6	26	43
Hard maple	41	2	3	5	10	18	34	52	66	82	102	62	0
Soft maple	133	18	39	61	84	117	132	155	187	171	200	138	136
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	26	0	1	8	18	25	27	34	37	28	45	30	15
Balsam poplar	3	5	4	4	4	2	2	3	1	2	6	10	88
Cottonwood	0	0	0	1	1	0	0	0	0	0	0	0	0
Bigtooth aspen	69	2	10	19	33	47	67	77	92	121	142	184	0
Quaking aspen	196	38	66	117	144	182	214	229	275	213	174	156	162
Basswood	17	0	4	5	8	13	15	19	25	31	9	10	133
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	7	0	0	0	2	5	6	10	12	9	13	8	0
Butternut	0	0	0	0	1	1	1	1	0	0	0	0	0
Elm	11	5	9	12	16	17	13	14	7	4	3	0	0
Paper birch	787	133	234	328	569	729	821	976	989	983	964	832	704
Other hardwoods	1	0	0	0	1	1	1	1	0	0	2	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	1,437	242	436	628	988	1,273	1,474	1,741	1,877	1,867	1,894	1,599	1,331
Total all species	1,717	290	501	725	1,134	1,447	1,704	2,038	2,277	2,392	2,484	2,248	1,675
Number of plots	1,288	27	53	82	123	174	216	227	195	118	51	16	6
Standard error	144	125	147	173	213	288	329	402	519	616	955	797	877
Average basal area	116	28	48	68	88	108	120	134	143	144	146	128	104

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 28.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Jack pine All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,213	0	399	488	720	937	4,709	2,536	5,432	9,826	0	0	0
Red pine	4,371	1,518	3,540	3,339	2,417	5,478	4,702	19,302	18,640	31,659	0	0	0
Jack pine	61,349	19,259	42,629	64,147	76,093	68,492	70,949	46,774	80,792	50,131	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	127	0	223	0	0	0	274	0	3,034	0	0	0	0
Balsam fir	94	0	0	0	352	0	0	0	0	3,830	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	4	0	22	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	0	0
Other softwoods	25	0	0	0	0	0	0	0	1,342	0	0	0	0
Total softwoods	67,183	20,777	46,813	67,974	79,582	74,907	80,634	68,612	109,240	95,446	0	0	0
Hardwoods													
Select white oak	564	242	269	178	411	1,315	414	0	1,978	0	0	0	0
Select red oak	1,522	64	756	0	2,899	2,129	0	0	11,219	7,798	0	0	0
Other red oak	7,025	766	3,389	2,922	4,866	14,208	11,472	5,038	15,358	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	363	0	137	134	279	754	381	0	2,330	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	48	0	95	0	137	0	0	0	0	0	0	0	0
Bigtooth aspen	727	248	1,084	105	0	1,223	2,076	0	0	0	0	0	0
Quaking aspen	5,007	1,348	2,375	3,696	9,437	4,621	5,024	8,669	1,866	6,314	0	0	0
Basswood	19	0	0	0	0	84	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	40	0	0	0	0	24	289	177	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	85	0	0	0	377	0	0	0	0	0	0	0	0
Paper birch	694	0	415	1,038	378	1,165	106	565	5,101	0	0	0	0
Other hardwoods	137	0	0	0	0	607	0	0	0	0	0	0	0
Noncommercial species	55	492	0	0	88	0	0	0	0	0	0	0	0
Total hardwoods	16,286	3,160	8,520	8,073	18,872	26,130	19,762	14,449	37,852	14,112	0	0	0
Total all species	83,469	23,937	55,333	76,047	98,454	101,037	100,396	83,061	147,092	109,558	0	0	0
Number of plots	261	19	47	38	59	59	28	5	5	1	0	0	0
Standard error	14,015	13,087	28,714	30,633	33,081	39,150	33,623	53,878	111,204	3/	0	0	0
Average basal area	71	22	48	67	84	84	85	69	110	80	0	0	0

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

[3/] Insufficient number of plots to compute the standard error.

Table 29.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Red pine All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	7,202	150	2,889	2,358	4,019	17,273	16,757	8,153	38,290	34,991	29,191	41,096	0
Red pine	93,627	7,292	61,938	136,674	125,539	105,323	98,542	77,374	84,962	104,210	83,749	74,535	0
Jack pine	5,107	143	1,215	6,470	7,793	11,218	8,390	9,288	7,365	0	3,056	0	0
White spruce	926	458	473	1,089	605	140	0	1,919	0	6,269	4,963	8,800	0
Black spruce	585	0	0	569	0	870	990	10,975	3,832	0	0	2,869	0
Balsam fir	1,351	110	0	117	1,914	133	2,363	18,398	3,425	2,461	7,970	11,665	0
Hemlock	348	0	0	0	0	0	0	0	7,724	0	5,824	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	110	0	0	0	0	0	0	0	0	3,810	1,333	0	0
Other softwoods	788	0	1,829	85	0	2,287	3,377	0	0	0	0	0	0
Total softwoods	110,044	8,153	68,344	147,362	139,870	137,244	130,419	126,107	145,598	151,741	136,086	138,965	0
Hardwoods													
Select white oak	341	0	948	263	9	0	697	0	0	0	1,002	0	0
Select red oak	2,253	251	1,689	0	1,948	438	17,595	0	4,530	10,549	6,392	3,959	0
Other red oak	3,471	16	5,326	5,841	2,678	0	5,120	0	0	2,092	1,984	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	43	0	0	0	0	0	0	0	0	305	1,327	0	0
Hard maple	1,162	474	747	0	2,312	2,595	0	0	4,700	6,158	1,215	3,358	0
Soft maple	2,348	0	449	0	644	11,678	0	594	15,528	25,459	5,463	17,751	0
Beech	81	0	365	0	0	0	0	0	0	0	0	0	0
Ash	133	0	441	0	0	396	0	0	0	0	101	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	1,108	0	258	477	2,835	0	0	4,913	6,190	3,649	1,993	3,378	0
Quaking aspen	5,575	30	3,992	2,214	11,800	5,088	5,226	14,952	24,415	6,178	5,019	11,197	0
Basswood	40	0	131	0	0	139	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	191	344	253	143	12	0	0	908	0	2,205	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	128	0	0	0	0	1,276	0	0	0	0	915	0	0
Paper birch	1,984	1,367	443	759	680	2,350	9,732	7,281	0	12,491	5,717	19,362	0
Other hardwoods	653	0	984	0	2,289	0	0	0	0	0	0	0	0
Noncommercial species	79	0	97	7	161	0	0	262	0	1,095	0	0	0
Total hardwoods	19,590	2,482	16,123	9,704	25,368	23,960	38,370	28,910	55,363	70,181	31,128	59,005	0
Total all species	129,634	10,635	84,467	157,066	165,238	161,204	168,789	155,017	200,961	221,922	167,214	197,970	0
Number of plots	211	24	47	51	40	17	11	4	5	4	6	2	0
Standard error	23,499	7,063	31,662	66,311	65,108	95,618	78,145	122,739	132,554	198,954	74,597	3/	0
Average basal area	100	9	65	127	130	127	124	116	138	145	115	128	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 30.--Biomass yields per acre in all live trees by species group[1] and stand-age class, All Units, Wisconsin, 1983

Forest type - White pine All sites

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	70,209	18,945	53,191	47,181	41,469	80,067	55,918	62,733	93,336	75,712	57,951	86,958	128,705
Red pine	12,680	4,676	12,027	18,951	16,368	18,105	11,344	20,814	15,890	6,998	9,126	13,840	5,391
Jack pine	4,284	0	0	4,849	6,164	5,420	10,893	9,722	4,205	1,750	0	4,533	0
White spruce	1,784	774	4,194	1,529	0	0	0	963	7,476	1,630	0	1,130	0
Black spruce	1,832	0	0	4,994	0	1,795	4,504	0	3,252	2,751	0	0	1,201
Balsam fir	4,821	319	2,044	0	0	0	647	874	8,887	12,701	0	1,792	16,028
Hemlock	1,251	0	0	0	0	2,813	0	0	2,107	1,121	0	1,624	4,897
Tamarack	445	0	0	0	0	0	2,184	0	0	809	3,488	0	458
Northern white-cedar	606	0	0	0	0	0	0	0	0	598	0	807	5,044
Other softwoods	86	0	0	0	0	0	812	0	0	0	0	0	0
Total softwoods	97,998	24,714	71,456	77,504	64,001	108,200	86,302	95,106	135,153	104,070	70,565	110,684	161,724
Hardwoods													
Select white oak	2,489	495	0	0	652	4,240	2,881	5,361	1,755	3,035	3,587	4,049	3,347
Select red oak	2,295	0	0	0	0	473	6,178	2,667	2,925	582	8,019	1,486	7,026
Other red oak	6,553	0	2,333	0	6,622	3,233	6,329	33,329	4,535	4,915	4,416	13,378	0
Hickory	162	0	0	0	1,828	0	0	0	0	0	931	0	0
Yellow birch	278	0	3,937	0	0	0	0	0	0	0	0	0	0
Hard maple	1,215	0	3,474	0	0	0	0	0	0	1,066	0	9,714	4,091
Soft maple	7,121	2,346	1,773	1,652	2,057	584	4,878	10,267	11,657	7,740	11,387	12,680	17,834
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	730	0	0	0	0	0	0	0	1,662	931	0	8,735	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	1,933	0	0	34,731	0	0	0	0	672	0	0	0	0
Bigtooth aspen	1,747	0	702	4,436	0	762	1,353	691	6,995	1,916	0	0	0
Quaking aspen	13,778	3,732	10,581	7,958	22,227	12,911	18,525	21,824	12,319	16,870	0	15,569	8,419
Basswood	407	0	0	0	0	0	944	0	0	376	0	0	2,636
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	27	0	0	0	0	0	0	0	0	203	0	0	0
Black cherry	933	318	1,570	236	1,090	191	0	2,795	346	980	0	5,758	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	339	0	884	1,579	0	953	601	0	0	276	0	0	0
Paper birch	5,873	0	0	1,462	2,249	7,500	6,670	0	9,957	10,975	0	6,010	11,645
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	383	0	0	123	0	0	87	0	177	916	3,441	3,550	44
Total hardwoods	46,263	6,891	25,254	52,177	36,725	30,847	48,446	76,934	53,000	50,781	31,781	80,929	55,042
Total all species	144,261	31,605	96,710	129,681	100,726	139,047	134,748	172,040	188,153	154,851	102,346	191,613	216,766
Number of plots	113	9	8	6	9	11	12	10	15	15	2	5	11
Standard error	23,330	16,965	46,727	74,295	54,121	58,534	57,697	90,401	108,502	58,682	[3]	130,775	105,817
Average basal area	100	28	86	96	83	110	100	117	121	106	73	120	124

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

[3] Insufficient number of plots to compute the standard error.

Table 31.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Black spruce   All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,744	77	2,942	718	2,333	1,936	337	0	7,358	3,566	3,202	0	0
Red pine	1,111	590	1,924	741	935	265	1,877	0	5,697	0	0	0	0
Jack pine	138	0	0	32	0	0	1,019	0	0	2,051	0	0	0
White spruce	230	0	0	135	0	243	0	0	3,377	0	0	0	0
Black spruce	43,529	22,289	32,603	33,434	53,458	70,524	44,732	49,730	62,191	96,001	17,702	0	7,137
Balsam fir	4,059	2,185	1,616	1,671	1,856	6,418	9,494	7,957	14,724	9,127	8,173	0	0
Hemlock	998	0	972	0	0	919	0	0	3,394	7,231	22,367	0	0
Tamarack	8,275	4,998	5,029	8,845	11,391	7,396	15,981	9,833	7,175	10,755	0	0	9,416
Northern white-cedar	1,803	385	2,267	84	0	1,992	855	2,828	6,941	11,792	12,837	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	61,887	30,524	47,353	45,660	69,973	89,693	74,295	70,348	110,857	140,523	64,281	0	16,553
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	524	325	312	1,052	0	1,384	0	0	0	0	0	0	0
Other red oak	40	0	0	0	0	0	0	0	821	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	552	24	487	278	0	298	1,718	1,225	1,778	3,086	0	0	0
Hard maple	367	0	0	492	0	1,295	0	0	1,816	0	0	0	0
Soft maple	1,524	0	1,192	445	234	2,672	4,826	5,517	4,436	0	5,694	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	50	0	0	0	0	0	0	892	0	0	0	0	0
Balsam poplar	74	0	0	0	0	0	0	1,328	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	474	0	0	1,261	238	0	0	0	2,164	0	0	0	0
Quaking aspen	5,258	4,429	2,455	7,528	4,913	7,181	9,441	2,403	5,013	0	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	192	0	0	0	67	0	0	845	1,096	0	5,861	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	2,352	166	2,590	2,572	2,229	3,597	2,500	3,025	3,005	2,224	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	11,407	4,944	7,036	13,628	7,681	16,427	18,485	15,235	20,129	5,310	11,555	0	0
Total all species	73,294	35,468	54,389	59,288	77,654	106,120	92,780	85,583	130,986	145,833	75,836	0	16,553
Number of plots	142	16	23	38	18	16	8	8	7	5	2	0	1
Standard error	16,249	28,111	33,186	38,851	53,547	52,743	57,460	50,050	87,189	98,609	3/	0	3/
Average basal area	60	30	46	48	65	86	76	69	106	120	63	0	15

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 32.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Balsam fir All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	2,075	1,668	351	648	988	2,379	2,526	540	3,663	851	10,027	22,044	3,203
Red pine	663	358	1,369	234	0	497	916	216	0	3,147	3,343	1,837	0
Jack pine	144	625	0	0	0	0	259	0	0	0	0	0	0
White spruce	5,168	990	1,788	2,813	7,646	7,761	7,118	3,027	10,387	8,300	5,206	12,209	1,594
Black spruce	3,587	2,509	1,427	2,943	4,216	3,942	3,570	4,368	11,553	0	0	9,645	0
Balsam fir	52,957	15,233	30,697	36,543	59,439	64,699	72,054	69,136	57,477	61,961	46,780	50,193	41,644
Hemlock	1,768	723	0	672	1,995	1,328	1,719	1,055	5,074	3,120	0	0	31,134
Tamarack	1,056	296	615	1,300	307	394	1,214	1,444	1,177	530	0	11,889	0
Northern white-cedar	8,879	2,759	8,112	5,203	15,323	8,565	8,229	11,382	14,448	15,524	0	6,927	34,044
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	76,297	25,161	44,359	50,356	89,914	89,565	97,605	91,168	103,779	93,433	65,356	114,744	111,619
Hardwoods													
Select white oak	47	161	0	0	340	0	0	0	0	0	0	0	0
Select red oak	230	254	473	0	0	938	132	0	0	297	0	0	0
Other red oak	30	0	0	0	0	0	0	0	0	805	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2,845	1,423	2,074	2,201	0	4,581	2,293	4,218	4,931	8,462	0	1,858	4,745
Hard maple	1,424	1,208	0	2,388	0	1,885	2,955	88	0	1,630	0	0	0
Soft maple	6,782	2,649	4,073	4,500	5,452	10,328	8,324	2,810	6,615	28,662	20,944	4,645	703
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	3,889	2,983	2,789	3,701	5,253	6,504	2,012	7,178	2,749	4,292	0	0	0
Balsam poplar	374	0	0	0	421	0	1,489	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	440	359	3,687	0	0	326	235	0	0	0	0	0	1,332
Quaking aspen	10,330	3,771	13,150	7,122	6,188	22,463	12,015	8,068	3,994	6,029	7,369	24,488	1,537
Basswood	48	0	0	207	0	0	0	200	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1,577	554	362	808	0	1,301	4,907	709	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	833	259	0	258	471	2,117	890	1,580	0	0	0	0	4,275
Paper birch	6,662	3,446	4,314	6,385	7,782	8,988	7,679	7,303	10,229	3,946	0	9,474	1,651
Other hardwoods	31	0	0	0	0	245	0	0	0	0	0	0	0
Noncommercial species	358	0	0	16	479	1,776	264	204	0	232	0	0	0
Total hardwoods	35,900	17,067	30,922	27,586	26,386	61,452	43,195	32,358	28,518	54,355	28,313	40,465	14,243
Total all species	112,197	42,228	75,281	77,942	116,300	151,017	140,800	123,526	132,297	147,788	93,669	155,209	125,862
Number of plots	213	29	16	24	16	27	49	27	8	8	2	4	3
Standard error	17,572	19,096	36,725	28,401	49,706	57,845	54,791	53,405	89,681	65,712	3/	88,457	90,936
Average basal area	85	33	60	61	93	111	105	94	105	105	68	107	115

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 33.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Northern white-cedar All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,835	1,343	0	0	1,673	982	1,906	643	811	825	3,548	412	5,241
Red pine	59	0	0	0	0	270	0	0	0	0	0	334	0
Jack pine	90	0	0	0	0	0	0	0	1,032	0	0	0	0
White spruce	1,568	0	682	568	0	1,737	3,097	2,588	1,818	1,206	778	1,992	1,356
Black spruce	4,767	7,851	1,900	4,439	3,057	4,545	3,101	6,574	3,946	5,781	2,683	275	9,586
Balsam fir	18,588	2,085	3,503	13,459	6,085	22,850	15,216	28,573	22,503	12,804	18,094	18,905	22,043
Hemlock	3,597	1,022	0	0	0	1,031	2,342	1,366	998	2,473	5,203	2,376	13,090
Tamarack	4,306	0	8,249	4,710	2,239	11,978	7,387	4,431	4,393	0	3,611	778	972
Northern white-cedar	79,177	15,595	52,406	59,705	35,920	71,595	73,513	93,050	77,150	71,984	99,533	90,371	92,053
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	113,987	27,896	66,740	82,881	48,974	114,988	106,562	137,225	112,651	95,073	133,450	115,443	144,341
Hardwoods													
Select white oak	34	1,462	0	0	0	0	0	0	0	0	0	0	0
Select red oak	119	0	0	652	0	0	0	0	923	0	0	0	0
Other red oak	72	0	0	586	0	0	0	0	434	0	0	0	0
Hickory	132	1,631	0	0	0	468	0	0	0	0	0	487	0
Yellow birch	4,860	0	0	0	3,799	1,934	4,112	3,391	3,490	4,969	5,441	6,480	12,385
Hard maple	377	0	0	0	0	0	0	55	0	1,066	1,429	462	385
Soft maple	3,944	4,216	7,897	2,193	6,900	987	4,988	3,261	5,431	3,467	6,154	3,322	3,037
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	8,130	0	1,443	2,593	6,073	2,384	4,705	10,059	10,671	6,290	9,488	12,124	15,317
Balsam poplar	308	0	0	0	0	265	0	412	0	0	1,451	551	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	354	0	0	0	0	0	3,047	622	0	0	0	0	0
Quaking aspen	3,502	1,216	4,731	0	9,670	7,189	8,007	5,202	2,982	1,943	882	3,458	388
Basswood	264	1,014	0	0	0	0	0	0	0	0	1,124	1,179	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	55	0	0	0	0	0	369	0	0	235	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	878	1,381	1,190	0	741	518	825	2,628	588	593	1,412	324	260
Paper birch	8,076	1,708	9,823	11,992	13,735	10,832	9,418	13,067	7,010	6,783	5,324	7,857	3,237
Other hardwoods	152	0	0	0	1,789	69	479	0	0	264	0	0	234
Noncommercial species	65	0	0	0	0	118	0	0	0	556	0	0	20
Total hardwoods	31,322	12,628	25,084	18,016	42,707	24,764	35,950	38,697	31,529	26,166	32,705	36,244	35,263
Total all species	145,309	40,524	91,824	100,897	91,681	139,752	142,512	175,922	144,180	121,239	166,155	151,687	179,604
Number of plots	171	4	7	10	4	20	16	19	15	15	22	14	25
Standard error	35,799	37,279	53,619	59,542	75,416	75,467	72,213	128,737	125,457	83,808	135,144	129,173	137,697
Average basal area	130	39	80	92	74	120	123	153	131	116	154	141	158

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 34.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Tamarack All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	2,088	1,859	1,458	680	305	1,377	2,587	2,180	6,749	2,093	0	17,778	0
Red pine	132	0	0	213	0	0	0	585	648	0	0	0	0
Jack pine	287	0	0	159	0	2,119	1,298	0	0	0	0	0	0
White spruce	515	492	0	1,068	0	628	352	586	0	0	0	0	7,640
Black spruce	7,511	6,328	4,097	11,738	17,406	8,176	9,139	3,638	6,555	2,497	0	18,823	1,866
Balsam fir	3,419	242	2,504	2,916	2,930	7,630	3,881	3,461	3,488	10,885	0	0	0
Hemlock	65	0	0	171	0	0	0	0	0	499	0	0	0
Tamarack	37,840	21,141	20,241	32,104	61,908	38,387	54,647	66,779	62,715	40,510	0	42,632	41,303
Northern white-cedar	995	238	0	320	0	396	1,172	1,102	4,237	6,072	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	52,852	30,300	28,300	49,369	82,549	58,713	73,076	78,331	84,392	62,556	0	79,233	50,809
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	62	462	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	159	0	301	237	0	0	0	0	562	0	0	710	0
Hard maple	130	0	597	0	0	0	0	0	0	0	0	0	0
Soft maple	2,452	1,590	761	2,606	1,705	3,674	5,762	3,260	7,481	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	497	0	0	0	0	0	0	2,063	4,822	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	845	1,402	0	0	0	7,353	1,336	0	0	0	0	0	0
Quaking aspen	2,304	246	2,578	1,438	1,534	10,903	0	3,456	1,374	2,153	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	82	0	0	240	0	408	98	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	490	0	0	0	1,278	1,468	0	0	1,781	2,742	0	0	0
Paper birch	3,628	3,562	2,026	1,621	3,571	11,899	3,270	5,795	6,611	799	0	3,825	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	10,649	7,262	6,263	6,142	8,088	35,705	10,466	14,574	22,631	5,694	0	4,535	0
Total all species	63,501	37,562	34,563	55,511	90,637	94,418	83,542	92,905	107,023	68,250	0	83,768	50,809
Number of plots	119	16	26	22	7	9	9	10	8	8	0	2	2
Standard error	11,587	17,280	16,404	36,046	52,967	54,746	51,655	45,532	60,125	40,539	0	3/	3/
Average basal area	50	29	28	45	72	70	65	68	79	57	0	71	43

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 35.--Biomass yields per acre in all live trees by species group and stand-age class, All Units, Wisconsin, 1983

Forest type - White spruce All sites

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	4,233	0	7,401	0	1,056	0	3,378	53,635	0	0	0	0	0
Red pine	817	0	1,397	1,068	1,720	0	0	0	0	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	90,976	3,286	48,198	132,018	179,496	95,655	120,859	105,522	0	0	0	0	0
Black spruce	558	0	0	822	2,247	0	0	0	0	0	0	0	0
Balsam fir	8,727	0	3,011	0	10,822	27,801	11,119	49,079	0	0	0	0	0
Hemlock	597	0	1,016	0	1,887	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	2,887	0	0	0	15,017	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total softwoods	108,795	3,286	61,023	133,908	212,245	123,456	135,356	208,236	0	0	0	0	0
Hardwoods													
Select white oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oak	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	814	0	2,150	0	1,655	0	0	0	0	0	0	0	0
Hard maple	2,034	0	2,593	0	1,489	9,959	0	0	0	0	0	0	0
Soft maple	2,805	0	0	0	14,588	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1,787	0	0	0	2,542	8,774	0	7,428	0	0	0	0	0
Balsam poplar	1,648	0	0	0	0	0	21,430	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	296	0	0	0	0	2,568	0	0	0	0	0	0	0
Quaking aspen	7,320	5,872	8,214	0	0	21,096	20,636	7,114	0	0	0	0	0
Basswood	190	0	0	0	0	1,650	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1,572	0	6,812	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	362	0	1,570	0	0	0	0	0	0	0	0	0	0
Paper birch	1,291	0	0	0	0	0	3,943	25,687	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total hardwoods	20,119	5,872	21,339	0	20,274	44,047	46,009	40,229	0	0	0	0	0
Total all species	128,914	9,158	82,362	133,908	232,519	167,503	181,365	248,465	0	0	0	0	0
Number of plots	26	5	6	4	5	3	2	1	0	0	0	0	0
Standard error	43,995	7,798	46,695	141,681	187,055	120,744	3/	3/	0	0	0	0	0
Average basal area	99	7	68	122	168	128	132	152	0	0	0	0	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 36.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Oak-hickory   All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,488	1,090	840	406	661	821	1,229	1,241	3,763	1,452	1,866	859	2,995
Red pine	703	545	859	302	1,965	528	552	893	533	2,512	291	63	0
Jack pine	2,758	4,423	4,258	3,762	6,690	3,708	3,032	3,136	1,232	824	2,589	370	217
White spruce	12	0	0	354	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	102	85	0	0	628	23	21	597	0	0	0	0	0
Hemlock	52	0	0	226	130	0	0	0	384	0	0	16	0
Tamarack	27	0	0	0	100	8	0	139	0	115	0	0	0
Northern white-cedar	5	0	0	0	0	0	0	55	0	0	0	0	0
Other softwoods	132	323	512	334	131	18	77	26	0	377	0	0	42
Total softwoods	5,279	6,466	6,469	5,384	10,305	5,106	4,911	6,087	5,912	5,280	4,746	1,308	3,254
Hardwoods													
Select white oak	25,322	6,437	12,239	16,931	19,646	19,858	20,226	27,680	25,700	37,674	43,773	37,972	49,397
Select red oak	42,157	7,320	12,897	17,676	19,729	44,428	61,719	39,896	56,588	54,419	44,887	64,471	48,685
Other red oak	32,987	21,601	18,314	28,081	40,512	45,521	38,041	52,515	36,721	32,209	22,488	19,290	23,317
Hickory	6,025	2,594	3,871	4,361	9,000	7,110	4,689	6,410	5,950	7,884	7,573	7,731	7,970
Yellow birch	94	0	0	0	113	0	86	151	519	43	0	0	105
Hard maple	3,260	371	299	259	1,338	1,931	2,264	3,375	7,221	4,153	4,835	8,617	3,574
Soft maple	6,661	1,041	636	1,480	5,269	9,403	10,654	6,445	11,408	6,754	5,226	6,177	6,820
Beech	21	0	0	0	0	0	0	0	111	0	0	131	0
Ash	1,490	190	580	415	913	773	2,087	1,524	2,205	2,872	2,226	2,178	1,437
Balsam poplar	48	0	0	0	0	0	331	0	0	0	0	0	0
Cottonwood	232	130	338	432	135	256	229	651	71	445	0	115	0
Bigtooth aspen	5,154	1,264	907	1,621	4,765	7,403	8,662	7,080	7,885	5,599	2,541	3,312	3,351
Quaking aspen	3,674	2,357	1,749	5,860	3,362	7,359	6,321	3,356	2,610	2,426	2,107	1,971	1,354
Basswood	2,587	497	339	1,277	1,073	2,066	2,802	1,931	2,604	5,108	3,419	5,472	4,143
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	624	726	0	340	189	324	499	451	813	1,061	1,061	450	1,443
Black cherry	3,029	995	1,608	2,818	4,458	4,615	2,342	3,473	4,189	4,049	2,734	2,843	2,805
Butternut	705	822	211	0	2,175	840	628	607	103	257	970	1,685	353
Elm	2,466	1,478	1,236	1,999	1,873	2,326	1,400	2,677	2,469	3,530	4,119	3,733	3,998
Paper birch	5,052	1,421	1,691	5,514	7,756	6,078	8,384	8,603	4,588	1,793	5,366	3,157	4,592
Other hardwoods	700	398	1,261	654	95	346	970	486	763	1,612	321	575	892
Noncommercial species	2,007	1,472	1,989	4,030	1,694	754	1,430	1,570	2,825	2,470	2,066	2,910	3,313
Total hardwoods	144,295	51,114	60,165	93,748	124,095	161,391	173,764	168,881	175,343	174,358	155,712	172,790	167,549
Total all species	149,574	57,580	66,634	99,132	134,400	166,497	178,675	174,968	181,255	179,638	160,458	174,098	170,803
Number of plots	1,199	148	65	41	53	142	177	116	117	90	64	98	88
Standard error	15,570	20,651	27,910	34,822	45,382	55,220	56,575	53,197	51,519	56,586	51,681	54,102	61,817
Average basal area	85	38	45	63	82	95	100	100	100	98	89	95	95

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 37.--Biomass yields per acre in all live trees by species group[1] and stand-age class, All Units, Wisconsin, 1983

Forest type - Elm-ash-soft maple All sites

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,297	144	298	772	825	1,818	1,517	2,531	1,267	3,010	493	1,078	1,928
Red pine	29	63	0	0	0	0	127	0	89	0	0	0	0
Jack pine	96	0	136	0	329	280	188	0	0	0	0	0	0
White spruce	488	79	307	118	650	525	252	1,061	567	929	595	218	553
Black spruce	311	50	0	395	776	225	448	733	0	125	0	834	270
Balsam fir	5,724	748	2,981	3,870	4,778	7,964	6,571	9,421	7,409	5,502	4,213	8,544	9,056
Hemlock	1,694	167	610	763	125	666	1,352	2,831	2,624	2,113	2,663	7,123	5,768
Tamarack	716	353	454	820	1,295	471	593	1,121	1,589	828	0	0	0
Northern white-cedar	3,909	1,388	1,360	2,190	1,866	3,559	2,109	7,094	8,798	3,578	3,185	5,204	10,815
Other softwoods	104	0	187	0	0	660	0	0	47	0	0	0	0
Total softwoods	14,368	2,992	6,333	8,928	10,644	16,168	13,157	24,792	22,390	16,085	11,149	23,001	28,390
Hardwoods													
Select white oak	1,802	1,502	1,646	365	2,668	914	1,053	1,132	3,512	2,702	4,155	2,552	672
Select red oak	1,762	335	1,194	379	912	2,263	2,468	1,963	2,550	2,376	3,907	3,731	385
Other red oak	1,003	438	970	0	1,087	1,076	1,775	302	3,904	0	0	698	0
Hickory	110	92	157	0	29	206	0	0	370	270	0	0	0
Yellow birch	3,337	57	790	3,137	2,691	2,219	3,418	5,197	5,862	3,103	606	8,507	12,374
Hard maple	2,532	162	1,409	1,000	2,687	1,908	5,608	2,482	2,471	3,702	6,026	5,026	928
Soft maple	29,223	8,233	13,231	16,325	25,577	31,671	40,872	33,961	45,199	38,773	38,366	42,336	34,117
Beech	61	8	0	0	0	0	0	0	473	189	0	0	0
Ash	33,106	8,214	13,972	37,538	35,759	31,400	33,693	39,235	43,191	40,566	63,197	44,907	49,268
Balsam poplar	606	580	182	869	1,402	663	107	1,488	421	0	0	670	0
Cottonwood	806	474	700	547	0	2,351	816	175	508	1,796	0	0	2,200
Bigtooth aspen	323	446	349	0	0	784	908	352	86	0	0	0	0
Quaking aspen	5,616	3,743	3,479	5,509	10,626	11,621	7,503	3,895	2,541	2,200	8,507	1,990	0
Basswood	2,291	1,344	319	383	356	4,017	1,796	2,260	4,352	2,667	3,011	6,498	2,319
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	49	302	0	0	0	87	0	0	0	0	0	0	0
Black cherry	649	400	506	40	1,110	1,655	289	870	512	479	265	184	316
Butternut	78	171	183	0	106	0	0	84	91	162	0	0	0
Elm	9,971	4,456	4,201	8,167	8,799	9,192	8,959	12,064	11,303	14,150	18,329	14,900	22,504
Paper birch	4,054	1,444	3,486	3,933	5,879	4,426	5,750	5,594	4,150	4,914	1,486	4,082	634
Other hardwoods	4,069	4,255	4,801	1,282	4,284	4,039	6,652	847	647	14,185	1,029	6,182	0
Noncommercial species	879	1,676	1,578	234	391	554	927	115	1,003	950	1,737	824	612
Total hardwoods	102,327	38,332	53,153	79,708	104,363	111,046	122,594	112,016	133,146	133,184	150,621	143,087	126,329
Total all species	116,695	41,324	59,486	88,636	115,007	127,214	135,751	136,808	155,536	149,269	161,770	166,088	154,719
Number of plots	606	77	56	40	56	76	59	67	60	42	26	26	21
Standard error	11,957	14,059	21,868	30,840	38,162	37,722	44,242	43,757	46,127	51,177	68,450	71,211	71,699
Average basal area	75	29	43	60	73	81	83	88	97	93	99	105	99

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 38.--Biomass yields per acre in all live trees by species group[1] and stand-age class, All Units, Wisconsin, 1983

Forest type - Maple-birch   All sites

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	2,314	386	2,302	1,621	2,021	1,265	2,116	2,806	2,807	3,013	5,076	1,943	5,062
Red pine	310	311	489	144	156	19	418	290	463	0	504	273	868
Jack pine	149	183	816	214	38	0	115	85	458	0	0	39	37
White spruce	457	93	569	370	529	415	435	606	462	422	748	560	438
Black spruce	124	44	129	29	92	206	62	257	261	0	0	245	0
Balsam fir	2,852	1,247	2,142	1,612	3,875	3,355	2,908	3,713	3,192	3,294	1,313	2,871	3,041
Hemlock	6,387	497	1,240	421	1,443	2,245	2,358	3,458	3,937	6,139	11,362	20,931	38,194
Tamarack	93	28	113	148	45	100	130	160	0	0	0	50	170
Northern white-cedar	1,131	208	337	200	234	614	840	1,429	785	1,145	1,822	2,870	4,213
Other softwoods	32	0	0	396	117	15	0	0	0	0	0	0	0
Total softwoods	13,849	2,997	8,137	5,155	8,550	8,234	9,382	12,804	12,365	14,013	20,825	29,782	52,023
Hardwoods													
Select white oak	2,332	1,813	3,171	2,271	3,042	1,404	2,269	1,728	3,043	3,398	3,599	3,005	1,931
Select red oak	8,668	3,254	4,432	7,215	8,448	8,862	11,056	9,151	9,678	13,325	11,272	8,937	7,190
Other red oak	992	800	2,466	2,571	915	430	1,339	611	1,098	135	1,223	406	585
Hickory	1,693	967	1,997	1,990	3,483	2,295	1,458	711	1,354	1,835	1,308	2,228	1,407
Yellow birch	6,817	827	2,670	1,952	4,802	4,711	4,808	7,421	7,227	10,389	14,039	13,055	19,149
Hard maple	50,593	13,258	12,422	19,364	34,795	49,807	55,842	63,263	71,547	70,288	72,189	66,980	77,471
Soft maple	20,111	9,232	14,962	18,364	22,742	27,572	25,144	24,591	17,674	18,911	18,556	17,265	7,953
Beech	972	90	815	2,677	149	151	205	689	526	1,195	809	3,521	3,556
Ash	7,529	2,563	1,832	6,331	7,107	9,529	9,045	10,361	11,287	8,975	6,494	6,983	4,010
Balsam poplar	113	13	0	0	584	89	204	35	202	75	234	0	0
Cottonwood	94	200	177	207	0	0	27	0	0	150	111	573	0
Bigtooth aspen	2,019	523	857	1,202	2,380	2,823	3,937	1,702	3,367	1,566	1,703	646	184
Quaking aspen	7,538	3,764	8,325	11,494	12,382	11,888	10,129	7,493	4,624	4,416	2,050	2,692	912
Basswood	14,711	2,195	3,803	9,372	12,009	20,537	18,817	22,256	16,572	17,563	13,833	11,636	10,652
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	111	0	0	332	204	5	253	39	273	81	0	172	0
Black cherry	2,384	1,521	3,364	3,423	3,601	3,038	2,509	1,718	3,832	1,729	1,501	1,662	415
Butternut	508	488	950	1,141	332	229	306	266	607	680	1,260	597	492
Elm	8,071	3,135	5,485	6,954	9,383	7,555	8,497	9,554	10,952	9,428	7,768	8,958	9,438
Paper birch	6,251	2,116	4,235	5,397	6,905	7,337	8,778	9,127	4,202	6,113	7,486	5,061	2,140
Other hardwoods	439	109	296	348	2,349	64	399	422	813	364	208	424	214
Noncommercial species	3,032	1,667	3,701	5,763	2,248	2,333	3,097	2,751	3,096	2,723	2,635	3,233	4,450
Total hardwoods	144,978	48,535	75,960	108,368	137,860	160,659	168,119	173,889	171,974	173,339	168,278	158,034	152,149
Total all species	158,827	51,532	84,097	113,523	146,410	168,893	177,501	186,693	184,339	187,352	189,103	187,816	204,172
Number of plots	1,887	156	130	111	113	281	313	234	116	112	73	117	131
Standard error	18,704	20,472	25,400	32,852	45,373	56,858	63,320	67,066	65,389	66,700	69,958	58,575	80,069
Average basal area	93	34	57	74	89	102	105	110	104	103	103	104	110

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

Table 39.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Aspen All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,246	608	524	545	916	1,096	2,337	3,161	4,274	8,103	0	0	0
Red pine	1,223	920	498	1,520	874	655	2,675	2,244	3,202	3,139	0	0	0
Jack pine	1,174	666	1,055	1,363	1,478	1,603	690	2,159	585	916	0	0	0
White spruce	849	380	435	938	918	1,027	1,322	1,014	1,052	2,914	0	0	0
Black spruce	351	300	419	405	179	353	606	317	0	0	0	0	0
Balsam fir	3,750	1,562	1,518	2,490	4,774	4,925	5,211	7,605	6,472	8,092	0	0	0
Hemlock	128	167	0	111	188	57	0	58	1,403	1,077	0	0	0
Tamarack	235	160	274	31	280	186	245	0	2,353	0	0	0	0
Northern white-cedar	486	183	116	184	349	397	1,309	835	3,194	243	0	0	0
Other softwoods	2	4	13	0	0	0	0	0	0	0	0	0	0
Total softwoods	9,444	4,950	4,852	7,587	9,956	10,299	14,395	17,393	22,535	24,484	0	0	0
Hardwoods													
Select white oak	1,606	862	1,007	1,207	2,378	1,915	1,614	2,953	2,541	1,523	10,404	0	0
Select red oak	4,946	1,425	1,915	2,706	3,880	6,708	9,649	12,365	4,175	15,472	51,558	0	0
Other red oak	2,266	1,524	917	1,777	1,735	3,134	3,323	1,016	9,896	2,447	27,077	0	0
Hickory	145	108	175	316	199	0	31	766	0	0	0	0	0
Yellow birch	467	147	79	329	348	697	846	1,298	682	1,091	0	0	0
Hard maple	2,830	1,206	992	2,853	2,488	3,780	4,113	6,813	5,122	4,913	0	0	0
Soft maple	10,652	4,848	5,403	6,768	11,053	15,837	16,380	16,417	9,900	22,505	0	0	0
Beech	25	2	0	0	0	115	0	0	0	90	0	0	0
Ash	1,579	700	1,028	1,274	2,421	1,872	2,101	2,460	2,021	27	0	0	0
Balsam poplar	748	208	214	274	706	739	1,776	1,772	1,177	4,737	0	0	0
Cottonwood	92	101	48	98	0	0	427	0	0	0	0	0	0
Bigtooth aspen	11,305	2,616	3,840	5,541	9,739	17,394	23,245	18,963	22,300	16,001	68,584	0	0
Quaking aspen	44,311	15,166	30,010	45,598	61,844	61,794	53,544	52,524	37,771	56,013	5,377	0	0
Basswood	980	214	1,130	476	967	1,440	1,480	1,935	263	389	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1,323	814	816	1,551	1,899	1,994	994	786	1,901	0	0	0	0
Butternut	53	0	0	0	41	75	120	332	0	0	0	0	0
Elm	1,152	680	587	1,107	1,415	1,170	1,559	2,953	794	803	7,717	0	0
Paper birch	10,664	3,319	4,730	8,177	12,438	15,019	19,932	13,663	10,324	12,094	21,108	0	0
Other hardwoods	123	104	184	83	278	105	54	0	0	0	0	0	0
Noncommercial species	910	613	624	1,205	1,214	1,085	784	845	1,200	1,366	0	0	0
Total hardwoods	96,177	34,657	53,699	81,340	115,043	134,873	141,972	137,861	110,067	139,471	191,825	0	0
Total all species	105,621	39,607	58,551	88,927	124,999	145,172	156,367	155,254	132,602	163,955	191,825	0	0
Number of plots	1,608	322	223	156	229	337	209	77	35	18	2	0	0
Standard error	14,833	16,063	21,335	31,440	40,810	48,626	52,385	53,507	50,884	70,500	3/	0	0
Average basal area	68	29	43	60	79	92	97	98	83	100	100	0	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Table 40.--Biomass yields per acre in all live trees by species group[1/] and stand-age class, All Units, Wisconsin, 1983

Forest type - Paper birch   All sites

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods													
White pine	1,920	1,698	973	321	3,209	592	2,673	3,585	3,247	5,770	0	0	0
Red pine	1,782	1,197	236	1,245	771	810	1,555	5,035	10,819	0	0	0	0
Jack pine	377	0	0	262	714	670	477	0	0	0	0	0	0
White spruce	1,545	0	0	2,463	193	1,757	2,480	1,260	422	52,336	0	2,943	0
Black spruce	427	600	0	583	0	322	941	313	329	0	0	0	0
Balsam fir	6,857	1,034	2,643	3,856	3,563	8,930	7,991	12,855	6,713	0	31,268	3,860	0
Hemlock	725	0	0	316	864	57	445	2,127	2,179	0	49,365	0	0
Tamarack	576	470	1,633	679	166	141	799	408	2,473	0	0	0	0
Northern white-cedar	1,163	0	839	549	906	2,093	632	1,237	4,370	0	0	2,355	0
Other softwoods	11	0	0	0	0	46	0	0	0	0	0	0	0
Total softwoods	15,383	4,999	6,324	10,274	10,386	15,418	17,993	26,820	30,552	58,106	80,633	9,158	0
Hardwoods													
Select white oak	2,219	1,683	4,885	206	4,388	2,183	1,265	1,876	2,051	0	0	3,183	0
Select red oak	11,241	3,610	3,813	4,117	9,678	10,786	18,783	16,810	12,875	0	0	0	0
Other red oak	914	0	743	273	1,781	927	640	488	6,536	0	0	0	0
Hickory	734	298	267	1,232	2,549	1,043	0	0	0	0	0	0	0
Yellow birch	985	18	134	1,813	190	1,107	1,349	1,113	1,453	0	17,110	0	0
Hard maple	4,588	340	1,255	651	3,196	4,384	8,446	7,561	7,425	0	0	0	0
Soft maple	14,016	2,637	11,490	12,637	9,641	17,906	18,471	15,226	6,863	0	58,084	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	2,329	87	1,089	2,132	3,747	3,351	1,395	2,320	5,304	0	0	3,596	0
Balsam poplar	194	518	0	0	321	126	0	260	0	0	0	7,588	0
Cottonwood	26	0	0	288	0	0	0	0	0	0	0	0	0
Bigtooth aspen	4,332	229	2,149	3,223	4,214	3,599	6,611	5,049	14,916	0	0	0	0
Quaking aspen	14,079	5,472	5,701	14,949	13,173	18,240	16,715	14,305	11,482	5,461	6,235	8,580	0
Basswood	1,107	0	640	1,280	1,192	1,221	1,936	384	0	0	0	5,772	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	790	857	769	236	470	1,272	728	752	713	0	0	0	0
Butternut	35	0	0	0	280	0	0	0	0	0	0	0	0
Elm	1,275	1,231	951	1,323	2,893	1,550	379	636	2,606	0	0	0	0
Paper birch	69,896	20,448	40,223	51,862	77,457	79,598	78,594	92,911	78,249	13,985	135,987	52,540	0
Other hardwoods	131	235	0	370	292	0	83	0	848	0	0	0	0
Noncommercial species	1,260	321	438	631	2,393	1,971	188	2,200	1,638	0	0	0	0
Total hardwoods	130,151	37,984	74,547	97,223	137,855	149,264	155,583	161,891	152,959	19,446	217,416	81,259	0
Total all species	145,534	42,983	80,871	107,497	148,241	164,682	173,576	188,711	183,511	77,552	298,049	90,417	0
Number of plots	322	27	26	29	41	78	68	40	9	1	1	2	0
Standard error	24,599	19,724	30,327	43,364	48,582	64,012	62,070	92,766	89,186	3/	3/	3/	0
Average basal area	88	28	54	69	87	100	103	113	110	56	155	57	0

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all plots in the forest type and index range.

3/ Insufficient number of plots to compute the standard error.

Hahn, Jerold T.; Stelman, Joan M.
1989. **Empirical yield tables for Wisconsin.** Gen. Tech. Rep. NC-131. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 46 p.

Describes the tables derived from the 1983 Forest Survey of Wisconsin and presents ways the tables can be used. These tables are broken down according to Wisconsin's five Forest Survey Units and 14 forest types.

KEY WORDS: Inventory, volume, growth.

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